8 m, x

15

MCR-72-41 (Vol II) Copy No.

FINAL REPORT

Space Shuttle Propulsion Systems On-Board Checkout and Monitoring System Development Study (Extension)

VOLUME II

GUIDELINES FOR INCORPORATION OF THE ONBOARD CHECKOUT AND MONITORING FUNCTION ON THE SPACE SHUTTLE

APRIL 1972

Contract NAS8-25619
DRL No. 187, Rev. A
Line Item No. 3 (Issue 2)

Prepared For

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MARTIN MARIETTA
DENVER DIVISION

MCR-72-41

Final Report

SPACE SHUTTLE PROPULSION SYSTEMS ON-BOARD CHECKOUT AND MONITORING SYSTEM DEVELOPMENT STUDY

VOLUME II - GUIDELINES FOR INCORPORATION OF THE ONBOARD CHECKOUT AND MONITORING FUNCTION ON THE SPACE SHUTTLE

APRIL 1972

Approved by

R. W. VandeKoppel
Program Manager

Contract NAS8-25619
DRL No. 187, Rev. A
Line Item No. 3 (Issue 2)

Prepared For

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MARTIN MARIETTA CORPORATION
Denver Division
Denver, Colorado 80201

FOREWORD

This final report was prepared by the Martin Marietta Corporation under extension to Contract NAS8-25619, "Space Shuttle Propulsion Systems On-Board Checkout and Monitoring System Development Study", for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The report is comprised of two volumes:

Volume I - Summary and Technical Results

Volume II - Guidelines for Incorporation of the On-Board Checkout and Monitoring Function on The Space Shuttle.

CONTENTS

Page

Page

Figure

1.0 SCOPE

1.1 Content - This document provides guidelines for incorporation of the Onboard Checkout and Monitoring Function into the designs of the Space Shuttle propulsion systems. Hereinafter, the Onboard Checkout and Monitoring Function is referred to as OCMF. These guidelines consist of and identify supporting documentation; requirements for formulation, implementation and integration of OCMF; associated compliance verification techniques and requirements; and OCMF terminology and nomenclature.

1.2 Applicability - These guidelines are directly applicable to the incorporation of OCMF into the design of Space Shuttle propulsion systems and the equipment with which the propulsion systems interface. The techniques and general approach as identified herein also are generally applicable to OCMF incorporation into the design of other Space Shuttle systems.

1.3 Intended Use - These guidelines shall be used by the National Aeronautics and Space Administration and the Space Shuttle contractors during the basic design phase of the Space Shuttle program. These guidelines shall be used to insure that the OCMF is incorporated into the basic design of the propulsion systems and associated interfacing systems. The applicable hardware, software and system design criteria documents and specifications shall incorporate the requirements of this document.

This page not used.

2.0 APPLICABLE DOCUMENTS

NASA

Number	Title	Date
Drawing 85M03885	Guidelines for Performing Failure Modes, Effects, and Criticality Analysis (FMECA) on the Space Shuttle.	09/28/71
SP-7012	The International System of Units, Physical Constants, and Conversion Factors.	1969

OTHER

Number	Title	Date
	National Bureau of Standards Technical News Bulletin, Vol. 48, No. 4, page 61.	April 1964

This page not used.

3.0 <u>REQUIREMENTS</u>

This section specifies the approach, constraints and considerations that shall be used in the definition and implementation of the OCMF.

3.1 Performance - This section specifies the functions that the OCMF shall perform, and the system analysis that shall be conducted to define the checkout and monitoring requirements.

3.1.1 Checkout and Monitoring Functions - The primary functions that comprise the OCMF for the Space Shuttle propulsion system are checkout, monitoring, control, and postflight evaluation.

Checkout shall be performed prior to each functional operation of the propulsion system (whether in flight or on the ground), during postflight safing and purging, and during maintenance operations.

Monitoring shall be performed during all phases of the Shuttle mission; that is, during preflight, inflight, postflight safing and purging, and maintenance operations.

Control shall be provided during all mission phases to start, stop, or otherwise regulate the operation of the propulsion systems.

Postflight evaluation shall be conducted during the interval between landing and maintenance operations. It is comprised of postflight evaluation of inflight data, inspections of the flight hardware, and checkout during postflight safing and purging.

3.1.1.1 Checkout - Checkout of the propulsion system consists of verifying its status, redundancy and operability. Checkout shall be performed prior to each start of propulsion system functional operation, during postflight safing and purging, and during maintenance operations.

3.1.1.1.1 Prestart Checkout - Prestart checkout shall verify that the propulsion system will meet its functional requirements during its next operation. The prestart checkout function is applicable to all phases (ground and flight) of the Space Shuttle mission that require propulsion system functional operations. The OCMF shall have the capability of performing verification of correct prestart status, avionics checks, redundancy verification and functional testing.

3.1.1.1.1.1 Status Verification - Prior to each operation of the propulsion system, the OCMF shall verify that the parameters associated with the elements of the propulsion system are within specified limits to ensure successful initiation of systems operation. Examples of such parameters include tank gas pressures and valve positions.

3.1.1.1.1.2 Redundancy Verification - Redundancy verification is the process of verifying that all redundant functional elements of the propulsion system and the elements associated with OCMF are operable. Complete redundancy verification shall be performed prior to each flight. For mechanical elements, the demonstration of normal functioning of the redundant elements in the previous flight, during postflight safing and purging, during maintenance retest, and/or during preflight operations shall be sufficient for redundancy verification. For the operational Space Shuttle vehicle, prestart checkout by functional tests for redundancy verification of mechanical elements shall be conducted only if the redundant element was not operationally verified during the operations mentioned above. However, capability shall exist in the basic design of the mechanical systems and the OCMF for redundancy verification by functional testing. The operability of the redundant paths in electrical and electronic elements shall be verified prior to flight. (This does not preclude inflight redundancy verification of electrical and electronic elements such as by self-checks.)

3.1.1.1.1.3 Avionics Checks - A complete prestart checkout of the electronic and electrical subsystems associated with the propulsion system and the OCMF shall be performed prior to each functional operation of the propulsion system. This checkout shall include such checks as verification of electrical power quality, data management subsystem self-checks, verification of the electrical elements of the sensors, and sequencing.

3.1.1.1.1.4 Functional Testing - The OCMF and the propulsion system shall have the capability for functionally testing the elements of the propulsion system prior to flight to verify redundancy and operability. The capability to test for internal and external leakage shall be included.

3.1.1.1.2 Postflight Checkout - Postflight checkout consists of the final assessment of the status and operability of the propulsion system before the maintenance cycle. It consists of monitoring the operation of the propulsion elements that are normally operated during the safing and purging operations. Verification of redundancy (of elements not operated in flight) and the lack of performance degradation are the principal objectives of this checkout. Proper operation of functional elements during this phase shall be sufficient to preclude preflight functional testing of those elements to verify operability or redundancy (unless an element has been affected by maintenance actions).

3.1.1.1.3 Maintenance Retest - The OCMF shall have the capability to verify the integrity of interfaces and readiness status of the Line Replaceable Units (LRUs) that are functional elements, following their installation during maintenance operations. This capability shall include verification of functional propulsion elements affected by the LRU maintenance. Capability shall be provided to accomplish the verification by performing functional and leak tests. Capability shall also be provided to control and monitor individual functional elements in or out of normal sequences. Capability for individual component test may be waived only by formal approval of the Procurement Agency.

3.1.1.2 Monitoring - Monitoring is the OCMF activity of data acquisition and processing, and is applicable to all phases of the Space Shuttle mission. The monitoring function, in accordance with the following guidelines, shall consist of fault detection, fault isolation, trend analysis, data recording, and display. The parameters to be monitored, and the intervals and frequencies of monitoring, shall be derived from the analysis defined in Paragraph 3.1.2.2.

Inflight monitoring shall be accomplished by onboard equipment without reliance on a data interface external to the vehicle.

3.1.1.2.1 Fault Detection - The fault detection function shall provide data for emergency detection, for redundancy management, and for the related crew displays. Fault detection shall be accomplished by onboard equipment for all failure modes identified by the Failure Modes and Effects Analysis of Paragraph 3.1.2.2. Exceptions shall be taken only with Procurement Agency concurrence and shall be documented as such.

Emergency detection is the detection of any condition requiring automatic action to avoid a potentially catastrophic effect, or detection of any condition requiring special precautions or emergency procedures by the crew. The OCMF shall provide emergency detection for loss or impending loss of critical functions and for flight safety parameters exceeding safe limits. Emergency detection shall be accomplished within a time interval which permits the necessary actions to be taken to preclude a catastrophic effect of the failure. The emergency detection provisions, including the associated caution and warning displays, shall comply with the redundancy requirements defined by the Space Shuttle program specifications.

3.1.1.2.2 Fault Isolation - Diagnosis for fault isolation shall be accomplished with onboard equipment for redundancy management control and for use in maintenance operations.

Redundancy management is comprised of reacting to the detection of a failure, impending failure, or other potential emergency condition by activating the appropriate redundant function, path or element. The capability for redundancy management shall be provided in the propulsion system and associated subsystems, including the capability for fault isolation to the lowest level (element, path or function) at which redundancy is provided. Fault isolation for redundancy management shall be accomplished as soon after fault detection as necessary to activate the redundant element, path or function before the fault progresses. Loss of redundancy shall be reported to the crew. Fault isolation shall be accomplished for maintenance operations by identifying the faulty Line Replaceable Unit (LRU) and recording the data.

3.1.1.2.3 Trend Analysis - The parameters to be monitored for trend data and the discriminants by which the data shall be evaluated shall be as identified by the analysis approach of Paragraph 3.1.2.2.3. The principal purpose of trend analysis shall be to identify progressive deviations or degradations in performance while the system is still within safe operating limits. The information derived from this short term trend analysis shall be used in managing redundancy by using redundant resources when trend analysis has predicted an imminent failure, and in support of maintenance operations by identifying elements which have an unacceptable probability of failure during the next operation or mission. Short term trend analysis shall be conducted by onboard equipment.

Long term trend analysis, such as the compilation of fleet trend data, can be performed by ground equipment or by onboard equipment. The extent to which long term trend analysis is accomplished by ground or onboard equipment shall be determined by conducting the tradeoff analyses identified in Paragraph 3.2.2.2.8.

3.1.1.2.4 Data Recording - Capability shall be provided for processing and recording propulsion system performance data, trend data, fault isolation data, and component operating history data. The data recording requirements shall be as defined from the analysis defined in Paragraph 3.1.2.2.3. The recorded data shall be formatted and identified as to time and parameter to allow efficient postflight processing for reduction and evaluation.

3.1.1.2.5 Display - Capability shall be provided for reporting information to the crew. The general guideline for inflight display is that priority shall be placed on displaying information necessary for crew action or caution and warning. Included in this category are notification of the detection or prediction of a fault when corrective actions or emergency procedures by the crew are required, and notification of any reduction in level of redundancy. Capability shall be provided to display (on a crew request basis) the fault isolation data on which automatic redundancy management decisions are made. The capability shall also be provided for displaying flight information relating to system status and performance, such as operating modes and propellant quantities.

3.1.1.3 Control - Propulsion system control is integrated with the onboard checkout and monitoring function. Control capability shall be provided to initiate, modify, terminate or otherwise regulate the operation of the propulsion system during all phases of the Space Shuttle mission. Specific control requirements shall be derived from the analyses identified in Section 3.1.2. In general, the propulsion system is controlled by stimuli originating in associated subsystems, such as ignition and thrust commands originating in the avionics and/or crew subsystems. While control signals are generally low level electronic signals at their origin, propulsion elements may require high energy stimuli from other systems such as the electrical, hydraulic, or pneumatic systems, or from ordnance.

3.1.1.4 Postflight Evaluation - The OCMF shall support the postflight evaluation activities required for the propulsion system. They include postflight data evaluation and postflight inspection.

3.1.1.4.1 Postflight Data Evaluation - Postflight data evaluation is the data processing and analysis activity required to transform flight recorded data into the forms required by the ultimate data users. Requirements for postflight data evaluation include the processing of inflight fault isolation and trend data to identify maintenance actions; processing of performance data to establish vehicle and fleet trends; and data compilation to accure operating histories on time and cycle sensitive components.

3.1.1.4.2 Postflight Inspection - Postflight inspection includes visual and manual inspections of the flight hardware for evidence of anomalies such as hot gas leakage and structural damage or degradation. While postflight inspection is not a function of the OCMF, it is essential to the identification of potential maintenance actions on the propulsion system and to the verification of the structural integrity of the propulsion system.

To maximize the effectiveness of the ground operations, the postflight inspection requirements shall be identified during the design cycles of the propulsion system and during the checkout and monitoring requirements analyses such that they may be integrated into the design of the propulsion system and into coordinated postflight evaluation procedures.

3.1.2 Systems Analysis Approach - The systems analysis approach specified herein shall be employed to ensure that the propulsion system design is consistent with OCMF concepts, and to define the propulsion system's checkout and monitoring requirements. The systems analysis shall be comprised of assemblage of propulsion system hardware and functional data, analyses of the propulsion systems and elements, and the identification of propulsion parameters for measurement. An iterative process shall be employed whereby the conceptual and preliminary designs of the propulsion system shall be refined to accommodate and incorporate the checkout and monitoring functions defined in Section 3.1.1, to eliminate propulsion system elements that are not amenable to fault detection and isolation with onboard equipment, and to provide an optimized complement of measurement parameters. The compliance verification checkpoints and documentation requirements of the systems analysis are specified in Section 4.0. Figure 3.1.2-1 illustrates the systems analysis approach.

3.1.2.1 Propulsion System Definition - A thorough definition of the propulsion system shall be assembled to provide a base for the system analyses. Requirements for approval and documentation of the propulsion system definition are specified in Section 4.0. The propulsion system definition shall be changed and documented in accordance with the iterative steps in the systems analysis.

3.1.2.1.1 Functional and Operational Criteria - Functional and operational criteria shall include the following:

(a) Program Requirements: specifications, constraints, guidelines, concepts and objectives to be adhered to and pursued in the formulation of the propulsion system and OCMF definition. These program requirements will be supplied by the Procurement Agency.

(b) Mission Requirements: for each mission phase (including the turnaround cycle) full descriptions including timelines, sequences of events, and objectives. The mission requirements will be provided by the Procurement Agency.

(c) System Requirements: complete descriptions of the propulsion system functional operating requirements on a mission phase basis. These descriptions shall include the modes of propulsion system operations and associated sequences, frequencies, and durations; the interface requirements of the propulsion system with the other vehicle systems; and the propulsion system interfaces with the launch facility, propellant loading system, and ground mechanical and electrical support equipment at the launch pad and in the maintenance areas. The baseline system requirements will be provided by the Procurement Agency.

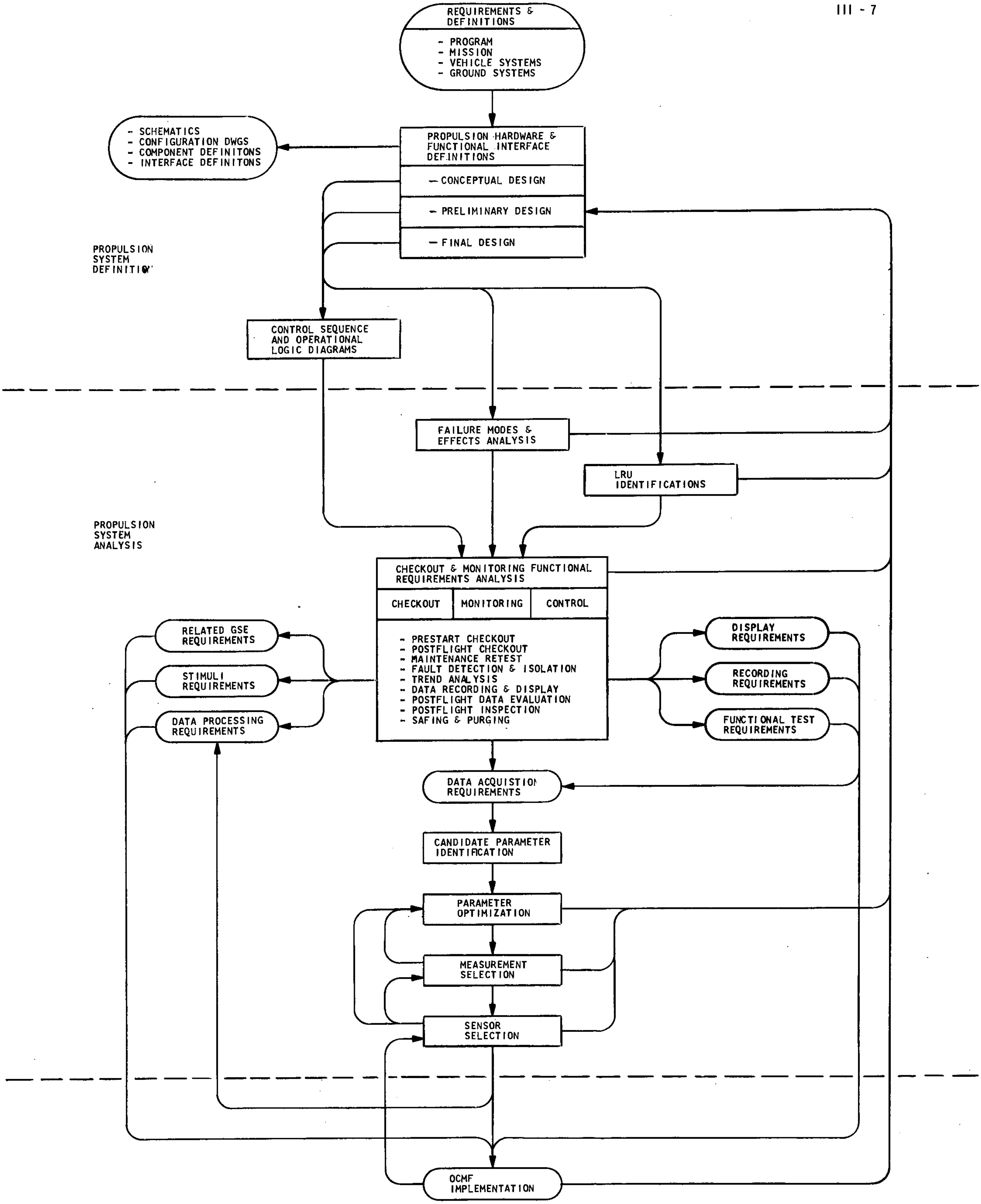

FIGURE 3.1.2-1 PROPULSION SYSTEM DEFINITON & ANALYSIS APPROACH

3.1.2.1.2 Propulsion Hardware Definition - Hardware definition shall consist of propulsion system schematics to the component level, system configuration drawings, and component definitions. The system configuration drawings shall define propulsion system interfaces with other subsystems, and shall show the physical arrangement and locations of the propulsion hardware within the vehicle. The component definitions shall contain operating characteristics and criteria in sufficient detail to permit the conduct of the component analysis. For example, the definition of a solenoid valve shall include the following characteristics for the final iteration of the propulsion system analysis:

- Weight, volume and envelope
- Operating and/or service fluids
- Operating, proof and burst pressure
- Opening and closing response times under specified conditions
- Performance margins
- Operating and service life ratings
- Environmental ratings
- Contamination control requirements
- Mechanical interface requirements
- Electrical interface requirements
- Special considerations unique to the design, construction, operation and service of the component

3.1.2.1.3 Control Sequence and Operational Logic Diagrams (CSOLD) - Control sequence and operational logic diagrams shall show the detailed sequences and conditions of operation of the propulsion systems. The diagrams shall contain entries for each sequential event and each condition required for a change of system, subsystem, assembly or component state, as well as the conditions necessary for continued operation in the same state. The accuracy with which a condition must be known shall be included.

All interfaces, modes of operations and redundancies shall be incorporated into these diagrams. The diagram shall encompass prestart, start, operating, shutdown and post-operation conditions. The feedback or influence of events and conditions on each other, the system operation, and interfacing functions shall be indicated. CSOLDs are a key source for establishing data acquisition, data processing, and stimuli requirements.

An example is presented below to demonstrate the general technique of generating CSOLDs, their basic content (not the required level of detail), and the integral relationship of checkout, monitoring, and control.

Figure 3.1.2-2 is a simplified CSOLD for the operation of an oxygen conditioning subsystem represented by Figure 3.1.2-3. For the purposes of this example, assume that prestart checkout has been successfully completed, the subsystem isolation valves (V1, V5, and V7 for Section 1) have been opened and verified, that under normal conditions only one section of the subsystem operates at any one time, and that the three identical sections of the subsystem are operated in progression so that each section can be expected to be operated during each flight.

The first block in Figure 3.1.2-2 represents the logic that enables the subsystem, selects the next section to be operated, conducts readiness checks, and opens the isolation valves. The times of subsystem operation start and stop are controlled by the pressure in T1 (see first and last decision diamonds). The frequency at which the pressure in T1 is required to be measured (sample rate) to determine when to start the subsystem will probably be considerably less than the rate at which it is sampled to determine when to shut the subsystem down.

The block labeled Subsystem A indicates that the value of the pressure in T1 may be required for other reasons, such as the fault isolation of another subsystem.

The operation of the selected section is initiated by opening the appropriate pump suction valve (V8 for S1). The verification of valve response may require the evaluation of parameters such as position, position versus time, line pressure, temperature, or solenoid current and/or voltage traces. The line labeled NO from the V8 Response question diamond (and the other abnormal condition lines) leads to fault isolation, subsystem or section shutdown, and redundancy management sequences.

If V8 responds properly, the start sequence is continued by commanding the gas generator oxygen feed valve (V2) open and verifying it. The remainder of the start sequence, represented by a

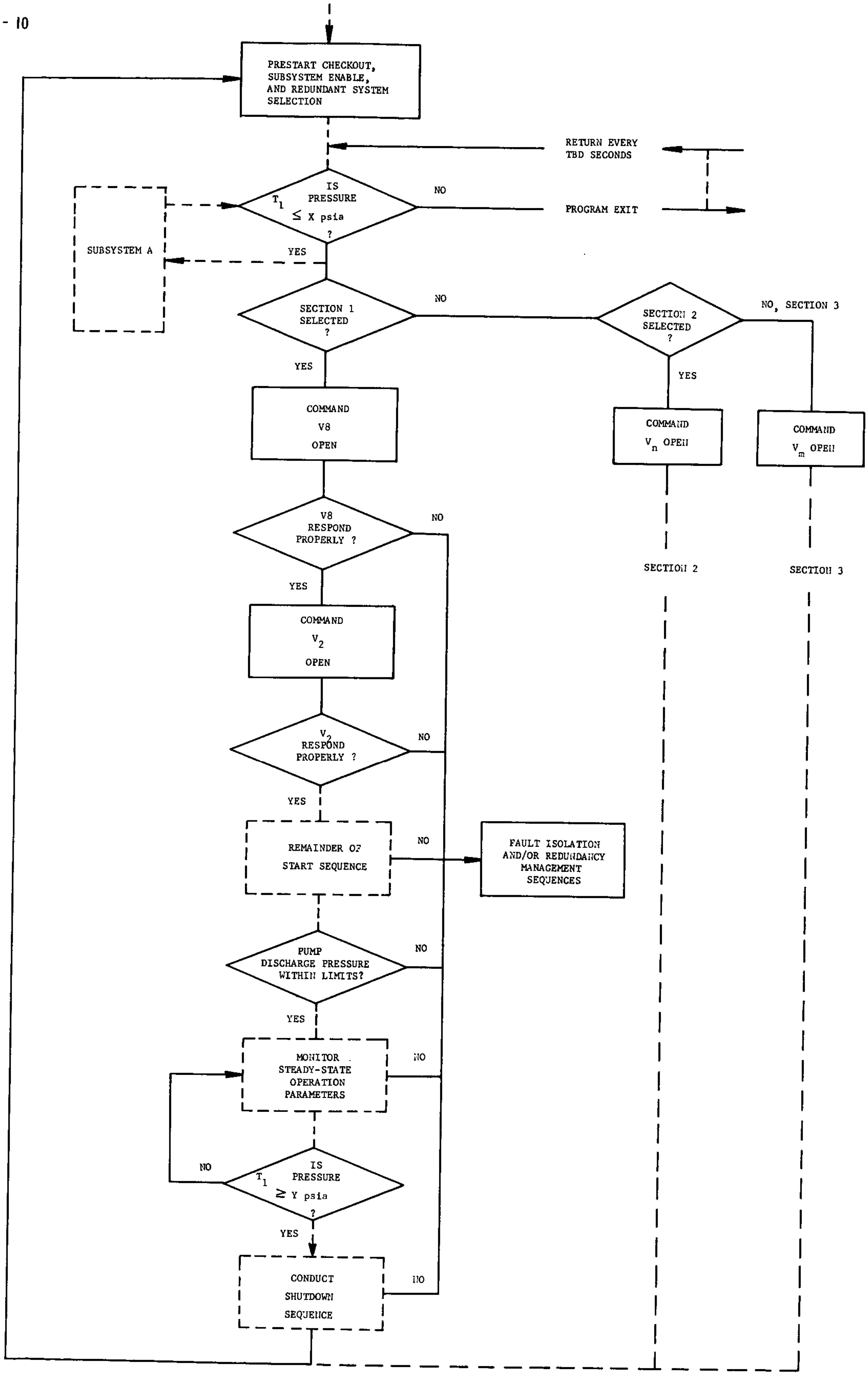

Figure 3.1.2-2 Simplified Control Sequence and Operational Logic Diagram

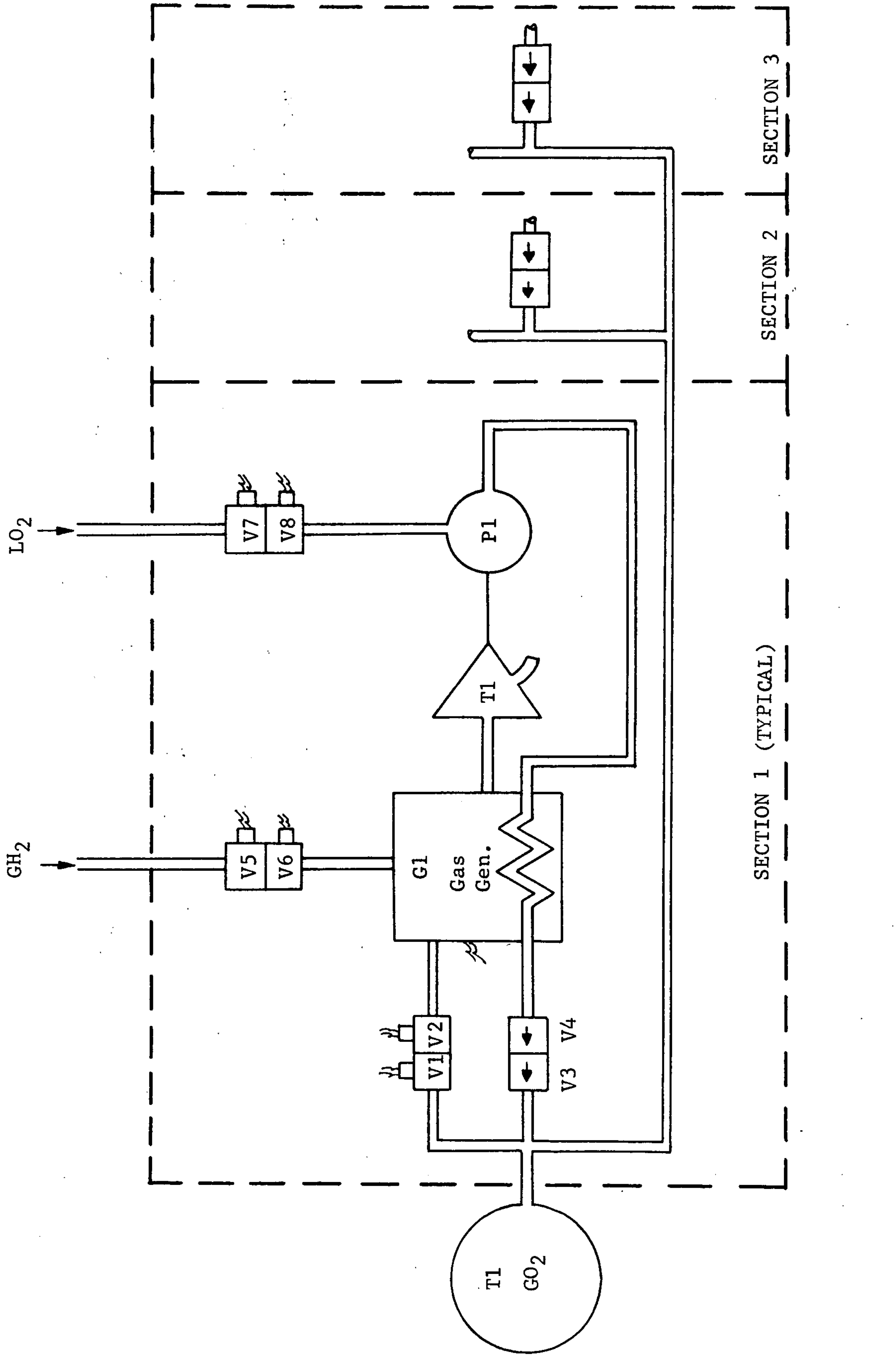

Figure 3.1.2-3 Oxygen Conditioning Subsystem

single block, would consist of opening the fuel feed valve (V6) and igniting the gas generator in the proper sequence. The timing and other conditions required to complete the start sequence shall be identified.

To fulfill the requirements of the monitoring function, a number of parameters may be monitored during steady-state operation, such as gas generator chamber pressure and temperature; turbopump speed and discharge pressure; power train lube level, pressure and temperature; power train vibration level, power train bearing temperature, etc. Some or all of these same parameters may be monitored at the same or different sample rates, at other times (during start, shutdown, etc.) for different reasons, and using the same or different discriminants to evaluate them.

The steady-state operation and monitoring would continue until either the pressure in T1 attained the specified level or until a fault was detected, at which time the appropriate shutdown, fault isolation and redundancy management sequence would be executed.

Fault isolation sequences shall be based on the LRU identifications (paragraph 3.1.2.2.1) and the level of redundancy of the system.

3.1.2.2 System Analysis - The checkout and monitoring requirements for the propulsion systems shall be defined by the system analyses approach described herein. The analyses of the propulsion systems shall be conducted by the propulsion design personnel in a coordinated effort with all other affected personnel. These analyses include line replaceable unit identification, failure modes and effects analysis, checkout and monitoring functional requirements analysis, and measured parameter and sensor selection. In addition to the identification of the required measured parameters and their associated sensors, the system analysis shall define data processing requirements, recording and display requirements, stimuli requirements, functional and leak test requirements, inspection requirements, and requirements for ground support equipment associated with checkout and monitoring.

3.1.2.2.1 Line Replaceable Unit Identification - Propulsion systems line replaceable units (LRUs) shall be identified. An LRU is defined as a component, group of components, assembly or subsystem that can be removed, replaced, and retested in the maintenance area by competent mechanics within the constraints of the Space Shuttle turnaround cycle timeline. All LRUs, except those that perform no function other than providing structural integrity, must be capable of being fault isolated. Exceptions shall be made only with formal approval of the Procurement Agency.

The identification of the LRUs shall be determined through trade-off studies. Selection considerations shall include accessibility, weight, volume, complexity of the structural, mechanical and electrical attachments, post-installation retest requirements, and fault isolation capability. Examples of LRU candidates are the gas generator or a valve package (V1, V2) of Figure 3.1.2-3.

3.1.2.2.2 Failure Modes and Effects Analysis - Failure modes and effects analysis (FMEA) shall be conducted to identify limitations in the propulsion system design (such as propulsion elements that are not amenable to fault detection with onboard equipment or require system break-in for checkout), to establish candidate parameters for fault detection and fault isolation, and to provide a basis for determining caution and warning display requirements. The basis for the FMEA shall be MSFC Drawing No. 85M03885, "Guidelines for Performing Failure Mode, Effects, and Criticality Analysis (FMECA) on the Space Shuttle", except that the criticality analysis defined therein is not required for propulsion system analysis for the OCMF. (This does not imply that the criticality analysis shall not be required by other parts of the contract.) The FMEA tabulation format, as presented in the referenced drawing, is shown in Figure 3.1.2-4.

The FMEA shall be iterated each time that the propulsion system design is modified during the system analysis and OCMF definition and implementation iterations.

3.1.2.2.3 Checkout and Monitoring Functional Requirements Analysis - This analysis, as outlined in Figure 3.1.2-1, shall derive the implementation requirements for the OCMF. The approach shall consist of evaluating the Propulsion System Definition (Paragraph 3.1.2.1), the LRU Identifications (Paragraph 3.1.2.2.1), and the FMEAs (Paragraph 3.1.2.2.2) to satisfy the checkout, monitoring, postflight evaluation, and control function requirements of the propulsion systems. The result of this analysis shall be the identification of requirements for display, recording, trend analysis, functional and leakage testing, data acquisition, stimuli, data processing, simulation, and related ground support equipment.

3.1.2.2.3.1 Description of Results

(a) Display Requirements - System status and hazard warning are the principal display requirements. The listing of display requirements shall identify: (1) any crew action required

FAILURE MODE AND EFFECTS ANALYSIS

END ITEM ________ PAGE ______ OF ______
SUBSYSTEM ________ DATE ________
FUNCTIONAL ASSEMBLY ________ BY ________

ITEM IDENTIFICATION	FUNCTION	FAILURE MODE	FAILURE REACTION TIME	MISSION OR OPERATIONAL PHASE	FAILURE EFFECT ON				FAILURE DETECTION METHOD	CORRECTIVE ACTION	CRITICALITY CATEGORY	REMARKS
					FUNCTIONAL SUBSYSTEM OR ASSEMBLY	END ITEM OR OTHER SYSTEMS	MISSION	CREW OR VEHICLE				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)

Figure 3.1.2-4 FMEA Tabulation Format

by the display condition; (2) the recommended type of display; (3) the mission time period or event for which the display is required; and (4) the required display redundancy based on the criticality of the condition being displayed. The derivation of the display requirements shall be accomplished per the guidelines of Paragraph 3.1.2.2.3.2.

(b) Recording Requirements - System status, system performance, fault isolation, and operating history data are the principal recording requirements. The identification of the data recording requirements shall specify: (1) the ultimate use of the recorded data; (2) the processing required (if any) prior to data recording; (3) the time of mission and period during which the indicated recording is required; (4) the peak rate at which the data must be recorded; and (5) the period for which recorded data must be retained. Recording requirements shall be derived per the guidelines of Paragraph 3.1.2.2.3.2.

(c) Functional and Leakage Testing Requirements - The identification of the checkout and monitoring requirements imposed by functional and leakage testing shall be included in the identification of the data acquisition, stimuli, recording, display, data processing, simulation and GSE requirements identified for the maintenance retest and ground checkout activities.

(d) Data Acquisition Requirements - Data acquisition requirements shall be defined in accordance with the analyses described in Paragraph 3.1.2.2.3.2. The recommended format of the tabulation of these requirements and an example (T1 pressure in Figure 3.1.2-3) of the information to be entered therein is illustrated by Figure 3.1.2-5.

The initial tabulation shall be made without regard to whether a parameter shall be obtained by direct measurement (measured parameter) or whether it must be calculated (derived parameter) from one or more measured parameters.

The data acquisition tabulation is a composite listing that defines the relationship between a parameter and a propulsion element, the basic discriminant for evaluating acquired data, the rationale for acquiring data, and the interval during which the data is of significance.

DATA ACQUISITION REQUIREMENTS

1 PARAMETER	2 PROPULSION ELEMENT	3 TIME OF DATA ACTIVITY	4 PARAMETER RANGE AND UNITS	5 ALLOWABLE ERROR	6 RESPONSE RATE	7 SAMPLE RATE	8 DATA USAGE
The entry shall uniquely identify the parameter by name, number, or identity code, and type (pressure, temperature, position, level, leakage are examples of parameter types).	The entry shall identify the propulsion component, assembly subsystem, and system with which the parameter is associated.	Entries shall be made describing the time interval, operation, or condition for which the data is meaningful.	The full scale range for the parameter shall be identified. Intermediate values expected under various conditions or operating modes shall also be identified. (Units specifications shall comply with the International System of Units.)	Allowable error is the total system uncertainty within which the value of the parameters must be known. Allowable error may be expressed in units or per cent of value. One entry shall be made for each entry of column (4).	This entry specifies the highest rate of change of the parameter which is required to be detected, measured, or reproduced. If subject to time of mission, operating mode or other conditions, separate entries shall be made for each rate. These entries may be specified in units per unit time or in frequency.	Sample rates shall be defined consistent with the response rate requirements of column (6) and with the reaction time requirements as defined by emergency detection requirements.	Entries shall be made to indicate the end usage of the data obtained from each parameter. Where data has more than one use and the time of data activity and sample rate are different for each use, a separate entry shall be made for each.
EXAMPLE: (Refer to Figure 3.1.2-3)							
PT1	T1	PS & PF C/O**	0-300 PSIA	± 5%	20 PSIA/SEC	5 SPS	FD & FI*
		Supply Mode	$200 \leq PT1 \leq 240$ PSIA	± 5%	10 PSIA/SEC	5 SPS	Control
		Resupply Mode	≥ 240 PSIA	± 5%	50 PSIA/SEC	10 SPS	Control
		Anytime Prop. Loaded	≥ 300 PSIA	± 7.5%	50 PSIA/SEC MAX.	5 or 10 SPS	Warning Display
		Safe & Purge	20 PSIA	± 2 PSIA	2 PSIA/SEC	5 SPS	Control
		**PS=Prestart PF=Preflight C/O=Checkout					*FD=Fault Detection FI=Fault Isolation

Figure 3.1.2-5 Format For Data Acquisition Requirements Tabulation

(e) Stimuli Requirements - Stimuli requirements are those necessary to satisfy the control function of the propulsion system elements. The specification of electrical requirements shall include signal identification, associated propulsion element, and applicable signal characteristics such as type, level, frequency, pulse width, repetition rate, duration, accuracy, time and conditions for application, maximum source impedance, minimum load impedance, and remarks that identify those conditions or characteristics not otherwise covered.

Propulsion system power requirements and sensor reference voltages are not included in these requirements. Power requirements shall be identified in the appropriate interface control documents, and sensor reference voltage requirements shall be identified from the sensor definitions of Section 3.2.

The specification of mechanical stimuli shall include all applicable characteristics such as force, torque, pressure, etc.

(f) Data Processing Requirements - Required algorithms, computations, comparisons, or other data processing techniques shall be identified for each usage of each identified propulsion system measured parameter, and for the execution of propulsion system control. These specifications shall include the frequency at which the processing is required and any limitations that may be imposed on processing time. Data processing requirements shall be identified per the guidelines of Paragraph 3.1.2.2.3.2 and 3.1.2.2.4.

(g) Related GSE Requirements - Ground support equipment related to the checkout and monitoring function includes those items necessary to support the activities of postflight checkout and evaluation, maintenance retest, and prestart checkout. The identification of these GSE requirements shall be a result of the analysis approach of Paragraph 3.1.2.2.3.2.

(h) Simulation Requirements - The validation of onboard computer programs and control sequences during preflight checkout requires the simulation of a number of propulsion parameters and conditions such as the simulation of engine thrust buildup, tank pressures, and so forth. Simulation requirements shall be identified in conjunction with the derivation of the prestart checkout requirements.

(i) Inspection Requirements - Propulsion system design requirements for inspection, inspection procedures, and related support equipment necessary to conduct postflight inspection shall be identified.

3.1.2.2.3.2 Derivation of Results - The results described in Paragraph 3.1.2.2.3.1 shall be derived in accordance with the analytical approach presented herein.

Checkout, monitoring, control and postflight evaluation are generally dependent functions. In most cases the requirements or capabilities necessary to perform those functions are most easily and effectively defined simultaneously. For example, the oxygen accumulator pressure in Figure 3.1.2-3 is monitored to control the operation of the oxygen conditioning subsystem in addition to being used for fault detection, fault isolation, and hazard warning display. Therefore, at the time that accumulator pressure is listed in the data acquisition tabulation, the corresponding data processing for fault detection, subsystem control, and display should be defined.

Data acquisition requirements shall be identified from two general sources. First, data acquisition parameters for fault detection, emergency detection and/or hazard warning display shall be identified for each recommended failure detection method identified from the results of the FMEA. The discriminants relating candidate parameters to specific failure modes shall be identified for each failure detection method. These discriminants are the basic source from which the corresponding data processing requirements shall be derived. Discriminants can be determined either by using the results (signatures) of extensive testing of acceptable and failed samples (including trend analysis) or by the understanding of the specific failure mechanisms determined by analytical techniques.

Second, data acquisition requirements for status and redundancy verification, functional and leakage testing, fault isolation, trend analysis, data recording and display, simulation, and control shall be derived from a phase-by-phase mission analysis using:

Control Sequence and Operational Logic Diagrams	(Para. 3.1.2.1)
Propulsion System Hardware Definitions	(Para. 3.1.2.1)
Propulsion System Functional and Operational Criteria	(Para. 3.1.2.1)
Checkout and Monitoring Function Definitions	(Para. 3.1.1)
LRU Identifications	(Para. 3.1.2.2)

Associated display, recording, data processing, ground support equipment and stimuli shall be identified concurrently with the identification of the data acquisition requirements.

The tabulation of candidate data acquisition parameters shall be optimized through the process described in Paragraph 3.1.2.2.4. (The optimization consists of measured parameter and sensor selection, and may include the iteration of the propulsion system design to add to or modify the propulsion hardware or modify operating sequences for the purpose of implementing the OCMF.) The tabulation shall include operational conditions such as manual control settings, mission elapsed time, burn time, or any other condition(s) that must be sensed to execute the checkout, control, and monitoring functions.

The following paragraphs and figures illustrate the derivation of the checkout and monitoring requirements on an individual function basis.

(a) Prestart Checkout - The prestart checkout function is defined in Paragraph 3.1.1.1.1.

The matrix shown in Figure 3.1.2-6 shall be used as a guideline to define the OCMF capabilities required for the prestart checkout function. The analyses indicated by this matrix shall be performed on a step-by-step basis for each mission phase in which prestart checkout is applicable.

The primary rows identify the requirements associated with the prestart checkout function (status verification, redundancy verification, etc.) and the columns identify the checkout and monitoring capabilities necessary to satisfy those requirements. The secondary rows identify the source material that must be analyzed to make this derivation. Notes providing supplementary information and definitions of the data source code acronyms are provided at the bottom of the figure.

The use of the matrix is illustrated below using the subsystem of Figure 3.1.2-3 as an example. The purpose of the examples in the following material is to demonstrate the analysis techniques and to create an awareness of the type of information to look for and consider. The examples should not be construed as conclusions or recommended solutions to specific requirements.

The X in the data acquisition column for status verification indicates that an examination of the control sequence and

FUNCTION REQUIREMENTS	DATA SOURCE \ CAPABILITY	DATA ACQUISITION	DATA PROCESSING	RECORDING	DISPLAY	STIMULUS	SIMULATION	GROUND SUPPORT EQUIPMENT
STATUS VERIFICATION	CSOLD, PHD	X						
	MPSP		X					
REDUNDANCY VERIFICATION[1]	CSOLD, PHD	X						
	MPSP		X					
	PR			X	X			
	CMFD			X	X			
FUNCTIONAL TESTING[1,2]	CSOLD, PHD	X				X	X	X
	MPSP		X					
	PR			X	X			
	CMFD			X	X			X
	PHD					X		X
FAULT DETECTION[3]	FMEA	X	X					
	MPSP		X					
FAULT ISOLATION[3]	FMEA	X						X
	LRU	X		X				X
	CSOLD, PHD	X				X		
	MPSP		X					
	PR				X			
	CMFD				X			
	PHD					X		
REDUNDANCY MANAGEMENT[3]	CSOLD, PHD		X			X		
	MPSP		X					
	PR			X	X			
	CMFD			X	X			
	PHD					X		

NOTES:

1. PREFLIGHT.
2. DEPENDENT ON OPERATING HISTORY OF LAST FLIGHT AND ON MAINTENANCE RETEST ACTIVITIES.
3. REQUIRED IF ANOMALY IS FOUND WHILE PERFORMING FIRST THREE FUNCTIONS.

DATA SOURCE CODES:

CSOLD: CONTROL SEQUENCE AND OPERATIONAL LOGIC DIAGRAMS
MPSP: MEASURED PARAMETER SEL. PROCESS
PR: PROGRAM REQUIREMENTS
CMFD: CHECKOUT AND MONITORING FUNCTION DEFINITIONS
PHD: PROPULSION HARDWARE DEFINITIONS
LRU: LINE REPLACEABLE UNIT DEFINITIONS
FMEA: FAILURE MODES AND EFFECTS ANALYSIS

Figure 3.1.2-6 Prestart Checkout Function Requirements
[illegible]

operational logic diagrams and the propulsion hardware definitions (schematics in this case) are necessary to identify the parameters needed to verify that subsystem status is within specified limits to initiate operation. The parameters in this case would be the positions of the six solenoid valves (closed), the pressures and temperatures of the GO_2, GH_2, and LO_2 supplies, gas generator igniter supply voltage (less than x), and possibly igniter current (less than w) and pump discharge pressure (y $\pm$ z) or temperature.

The X under data processing for the parameters identified above would be derived from the measured parameter selection process in which a determination of whether a desired parameter can and should be measured directly or can and should be derived from one or more measured parameters. Considerations that influence this determination are whether or not it is possible to directly measure the desired parameter and the fact that the desired information may be available from alternate parameters that must be measured for other reasons. Another driving factor in this determination is the objective to define the most cost effective system that will satisfy the requirements. Examples in the subsystem under consideration are the positions of the pump suction valves (V7, V8). Assume that all that is required to be known (for all reasons) is that the valves are either closed or sufficiently open to allow an adequate flow of LO_2 to the pump. A number of candidates are available for consideration either individually or in combinations. (1) Discrete position indicators; in this case the data processing is at a minimum since the transducer evaluates position directly and provides a go/no-go indication. This option would be most attractive if software design and/or computer speed or memory size were the principal cost drivers and the transducers were available. (2) Solenoid current signatures and pump inlet pressure and/or temperature where the inlet parameters were required for another purpose. The data processing for this case would consist of analyzing the current signatures with the appropriate discriminants (rate, level, rise time) and the inlet conditions. This option would have appeal if suitable position indicators were unavailable and development costs were high, or were not cost effective on the basis of considerations such as weight, or were not capable of being fault isolated. (3) Ultrasonic contact sensors may be required to detect internal or external leakage. They may be used in conjunction with solenoid current signatures or with pump inlet parameters. As in example (2) above, the data processing would entail the analysis of signatures and the evaluation of inlet parameters. The selection rationale would be similar to example (2).

Note 1 indicates that redundancy verification is required during prestart checkout prior to flight (not in flight). Paragraph 3.1.1.1.1.2 further indicates that normal functioning of redundant mechanical elements demonstrated during the previous flight, postflight safing and purging, maintenance retest, and/or during preflight operations shall be sufficient for redundancy verification. Assume that only sections 2 and 3 of the subsystem in Figure 3.1.2-3 had been operated during the previous flight. Then the operability of section 1 would require verification on the ground before the next flight. It may be verified through normal operation if that subsystem is normally started on the ground and section 1 is the next sequential section to be operated, or it may be verified by functional testing. (Capability shall be provided for functional and leakage testing in any case.) Whether or not the section had operated on the previous flight the solenoid valves would probably have been functionally operated during the postflight safing and purging cycle. Therefore redundancy verification may be limited to the verification of each check valve, the ignition circuitry, the turbopump assembly, and the electrical elements of the instrumentation. The verification of the operability of the check valves may require the addition of a pressure port between the valves to facilitate checkout. In this case the propulsion system analysis would be iterated to include the new component, as it would be to include any modifications to the basic design to facilitate functional testing of the turbopump assembly.

The X's under data acquisition and data processing for redundancy verification have the same meaning as they do for status verification. The X's under recording and display for redundancy verification indicate that the recording and display capabilities for redundancy status shall be identified in accordance with the program requirements and the checkout and monitoring function definitions

(Section 3.1.1). For example, the loss of redundancy shall be displayed to the crew and recorded for maintenance operations in the form of faulty LRU identification.

The remainder of the matrix shall be used in a similar fashion. The identification and implementation of the propulsion system checkout and monitoring requirements is dependent on a comprehensive understanding of the data source material, a systematic and thorough system analysis, and a coordinated effort among personnel of a variety of disciplines from the conceptual design through the final design of the propulsion and associated systems.

(b) Postflight Checkout - The postflight checkout function is defined in Paragraph 3.1.1.1.2. The capabilities required for this function are analogous to those for prestart checkout, described in paragraph (a) above, and for monitoring, described in paragraph (d) below, and shall be derived in a similar manner. An additional item to consider during postflight checkout is the potential desirability or requirement to confirm certain faults that were identified inflight. This may preclude the possible time consuming removal and replacement of operable hardware by conducting a relatively short checkout sequence. Or, ground fault isolation may be required for certain faults that were unable to be isolated to an LRU level inflight (such as an open electrical circuit).

(c) Maintenance Retest - The maintenance retest function is defined in Paragraph 3.1.1.4.

The checkout and monitoring capabilities required for the verification of the leakage integrity of interfaces and the status of replaced propulsion system LRUs shall be identified using the same approach and from the same sources as defined for the prestart checkout and monitoring functions.

The processing requirements for maintenance retest shall include the identification of the processing necessary to update the operating history records that are used to forecast scheduled maintenance activities and to establish functional testing requirements.

Simulation requirements requisite to LRU status verification shall be derived from the control sequence and operational logic diagrams. For example, the status verification of a replaced LRU in the subsystem of Figure 3.1.2-3 may require the simulation of the build-up and decay of gas generator chamber pressure or the simulation of pump inlet temperatures, etc.

Ground support equipment requirements associated with the verification of the leakage integrity of the interfaces and status of replaced LRUs shall be identified by this analysis.

(d) Monitoring - The monitoring function is defined in Paragraph 3.1.1.2.

The matrix shown in Figure 3.1.2-7 shall be used as a guideline to identify the OCMF capabilities required for the monitoring function. The analyses indicated by this matrix shall be performed on a step-by-step basis for every mission phase.

The format and use of this matrix is analogous to that described for the Prestart Checkout Function Requirements Matrix of Figure 3.1.2-6.

(e) Control - Stimuli requirements and data processing requirements necessary to satisfy the propulsion system control function shall be identified. Stimuli requirements are primarily derived from the propulsion component definitions described in Paragraph 3.1.2.1.2 while the data processing requirements are primarily derived from the control sequence and operational logic diagrams. The data processing requirements shall include the identification of parameter discriminants on which the control sequences are based and the dependence on such variables as mission elapsed time, operating mode, manual control settings, etc.

(f) Postflight Evaluation - The postflight evaluation function is defined in Paragraph 3.1.1.4. The onboard processing capability that shall be provided for postflight data evaluation shall be defined in conjunction with the definition of the onboard recording capabilities for fault isolation data, performance data, trend data, and operating history data. The processing capability shall be compatible with the selected recording techniques and the requirements of the data users. Related onboard control and display requirements, ground interfaces and ground support equipment shall be identified from the resultant processing implementation definitions and the data user requirements.

FUNCTION REQUIREMENTS	DATA SOURCE \ CAPABILITY	DATA ACQUISITION	DATA PROCESSING	RECORDING	DISPLAY	STIMULUS	GROUND SUPPORT EQUIPMENT	SIMULATION
FAULT DETECTION	FMEA	X	X					
	MPSP		X					
FAULT ISOLATION	FMEA	X					X	
	LRU	X		X			X	
	CSOLD, PHD	X				X		
	MPSP		X					
	PR				X			
	CMFD				X			
	PHD					X		
REDUNDANCY MANAGEMENT	CSOLD		X			X		
	MPSP		X					
	PR			X	X			
	CMFD			X	X			
	PHD					X		
CAUTION AND HAZARD WARNING	FMEA		X					
	CSOLD		X					
	MPSP		X					
	PR				X			
	CMFD				X			
TREND ANALYSIS	FMEA	X	X					
	PHD	X						
	MPSP		X					
	PR			X				
	CMFD			X				
PERFORMANCE DATA RECORDING	PHD	X						
	CSOLD	X						
	MPSP		X					
	PR			X				
	CMFD			X				
OPERATING HISTORY COMPILATION	PHD	X						
	CSOLD	X						
	CMFD	X		X				
	MPSP		X					
	PR			X				
SYSTEM OPERATION STATUS DISPLAY	CSOLD, PHD	X						
	PR	X			X			
	CMFD	X			X			
	MPSP		X					
CONTROL	CSOLD, PHD	X			X	X		
	MPSP		X					
	PR				X			
	PHD					X		
FUNCTIONAL TESTING[1]	CSOLD, PHD	X				X	X	X
	MPSP		X					
	PR			X	X			
	CMFD			X	X		X	
	PHD					X	X	

NOTES:

1. Dependent on operating history of last flight and on the maintenance retest activities.

DATA SOURCE CODES:

CSOLD: Control Sequence and Operational Logic Diagrams
FMEA: Failure Modes and Effects Analysis
MPSP: Measured Parameter Selection Process
LRU: Line Replaceable Unit Definitions
PR: Program Requirements
CMFD: Checkout and Monitoring Function Definition
PHD: Propulsion Hardware Definitions

Figure 3.1.2-7 Monitoring Function Requirements Derivation Matrix

While postflight inspection is not a function of the OCMF, the related propulsion system design requirements, inspection procedures, and support equipment shall be identified in conjunction with the propulsion system analysis to achieve a fully integrated design and a coordinated postflight phase.

3.1.2.2.4 Measured Parameter and Sensor Selection - This process shall consist of data acquisition parameter optimization, measured parameter selection and optimization, and candidate sensor selection.

The data acquisition parameter tabulation described in Paragraph 3.1.2.2.3.1 shall be optimized by eliminating non-essential parameters and eliminating parameters for which the same or better information is available from alternate sources. This is not a restriction on the use of redundancy either through the use of redundant sensors or by use of alternate parameters. Records shall be maintained to make visible the rationale justifying the retention or elimination of parameters.

The optimized data acquisition tabulation consists of a listing of measured parameters and derived (calculated) parameters. A measured parameter list shall be generated by selecting measured parameters for the derived parameters and adding them to the measured parameters listed on the optimized data acquisition parameter tabulation. A number of candidate measured parameters may exist from which a derived parameter may be obtained. (For example, volumetric flow rate, time, and propellant temperature, i.e., density, is a set of candidate measured parameters for deriving the parameter propellant quantity.) All measured parameters and sets of measured parameters which are candidates for deriving the required parameter shall be tabulated. The final selection of measured parameters for those cases where alternatives exist shall be made in conjunction with the implementation tradeoffs and selections of Section 3.2. (A driving factor in this selection is the relative cost effectiveness of the available sensor candidates and the other capabilities associated with a particular implementation candidate.)

The total list of measured parameters shall then be subjected to an optimization process. This process shall eliminate non-essential measured parameters and shall eliminate those entries for which better information is available and has been identified.

Candidate sensors shall be identified for each entry of the measured parameter tabulation. Final sensor selection shall be based on availability and the implementation criteria described in Section 3.2. In a case where a candidate sensor is not available, an iteration of the measured parameter tabulation is required. If alternative measured parameters cannot be identified, the baseline propulsion system shall be evaluated to determine whether or not the sensor requirement in question can be eliminated by propulsion redesign. If propulsion redesign is a viable option, then all of the foregoing analyses of this section shall be included in the iteration cycle. If propulsion redesign is not a viable option, then a sensor technology requirement shall be identified.

Fundamental data processing requirements shall be identified for each measured parameter. These requirements shall identify the discriminants by which each usage of each measured parameter shall be evaluated during the time of its significance; the frequency at which the processing for each case is required; and the restrictions on processing time for each case. The allocation of processing capability and its implementation shall be per the guidelines of Section 3.2.

3.2 Checkout and Monitoring Function Implementation - The guidelines delineated in Paragraph 3.2.2 shall be used to incorporate the propulsion checkout and monitoring function requirements into the implementation criteria of those onboard and ground equipment elements (defined in Paragraph 3.2.1) that perform or contribute to propulsion checkout, monitoring and control.

An integrated approach between the propulsion and avionics disciplines shall be followed to achieve the optimum implementation of the propulsion checkout and monitoring requirements. A coordinated effort shall be conducted to integrate the selected sensors into the propulsion system design; minimize unique propulsion stimuli and excitation requirements; minimize unique specifications that result in special sensors, measurement techniques, displays, crew operations, etc.; select measured parameters and techniques that best satisfy the requirements; and resolve situations where the requirements of the baseline propulsion system are not amenable to available checkout and monitoring techniques. If propulsion system configuration changes are necessary to achieve the objectives of this effort, then the analyses of Section 3.1 and this section shall be iterated for the affected hardware.

3.2.1 Elements Related to Checkout and Monitoring - The propulsion checkout and monitoring function requirements shall be incorporated into the propulsion system design and into the implementation criteria of the propulsion system sensors, the data management and control (DM&C) subsystem, the crew controls and displays, interfacing systems such as the hydraulic, pneumatic, and electrical systems, and the related ground support equipment (GSE).

3.2.1.1 Propulsion System Elements - Propulsion system element additions and/or modifications shall be made as required to make the system amenable to checkout and monitoring. Examples of such configuration changes include adding a bleed port downstream of a check valve to verify check valve operation; changing a bearing type to one for which failure detection methods can be implemented; or relocating sensor installations to ensure that the selected location is satisfactory for obtaining the desired information. The propulsion system shall be continually evaluated during the identification and implementation of the checkout and monitoring requirements to ensure that its design minimizes the checkout and monitoring requirements, and is completely compatible with the implementation of those requirements.

3.2.1.2 Sensors - Sensors respond to the measured parameters of the propulsion subsystems and of the propulsion dedicated controls and provide outputs in a usable form to remote processors, or to the subsystem interface units of the DM&C subsystem, or directly to the vehicle central computer complex via the vehicle data bus. Basic identification of candidate sensors, including type, range, allowable system error, and response, are made for the measured parameters identified by the analyses of Section 3.1. Generation of final sensor specifications shall be made in conjunction with the allocation of functional capabilities to the DM&C subsystem elements in accordance with the guidelines of Paragraph 3.2.2.

3.2.1.3 Interfaces - The implementation of the checkout and monitoring function for the propulsion system shall include the consideration and definition of interfaces with other onboard systems that involve propulsion checkout or control, such as the electrical and hydraulic systems.

3.2.1.4 Ground Support Equipment (GSE) - The extent to which the propulsion system checkout and monitoring function is implemented by the use of ground support equipment shall be determined using the criteria and considerations identified in Paragraph 3.2.2.

3.2.1.5 Data Management and Control (DM&C) Subsystem - The elements and configuration of the DM&C subsystem shown by bold blocks in Figure 3.2.1-1 are employed by this document to illustrate the relation of the DM&C subsystem to the pertinent vehicle and support equipment elements. The degree of applicability of this configuration or others is dependent on final criteria and requirements defined for the overall avionics system.

3.2.1.5.1 Central Computer Complex (CCC) - The central computer complex provides data processing capability for the Space Shuttle vehicle. The degree to which the CCC shall provide processing capability for propulsion system control, data evaluation, display, recording, functional testing and trend analysis shall be determined using the requirements of Section 3.1 as criteria, and the guidelines of Paragraph 3.2.2. The CCC shall store the propulsion system flight programs that are not stored in propulsion dedicated processors. It may also be used to store propulsion system data that is required to be retrievable during flight.

3.2.1.5.2 Digital Data Bus - The vehicle data bus system provides the data communication link between the central computer complex and other DM&C subsystem units. The implementation of the digital data bus (or alternate data transportation means) shall accommodate the propulsion system requirements and shall be compatible with the allocation of capabilities as identified from the tradeoffs described in Paragraph 3.2.2.

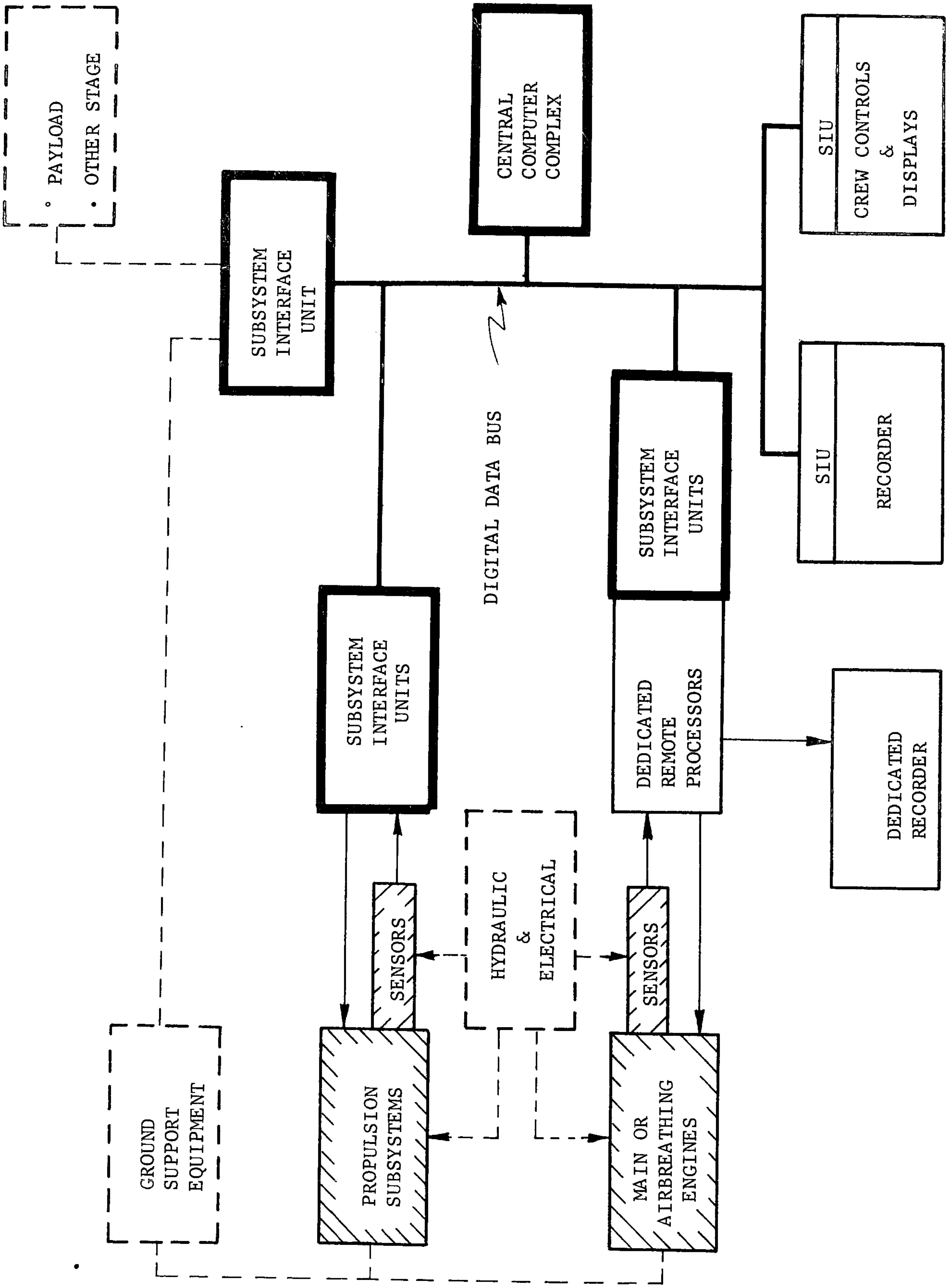

Figure 3.2.1-1 Elements Related to Propulsion System Checkout and Monitoring

3.2.1.5.3 Subsystem Interface Unit (SIU) - SIUs form the interfaces between the digital data bus and the elements of the user subsystems, and between the digital data bus and remote units of the DM&C subsystem. The general functions of an SIU related to propulsion subsystems are control and data acquisition. For the configuration shown in Figure 3.2.1-1, these functions include capabilities to receive and decode digital data bus transmissions, generate and apply electrical stimuli to selected points of propulsion subsystems for control, acquire data from selected points of propulsion subsystems, and condition subsystem data as required to transmit intelligible responses to the CCC. Electrical power conditioning and distribution for propulsion system control reference voltages may also be implemented by SIUs.

The extent to which SIUs shall perform data processing on propulsion systems data, and the extent to which SIUs shall be required to condition propulsion system data shall be determined through tradeoff analyses. Paragraph 3.2.2 contains criteria that shall be used as a guide in defining the allocation of capabilities to SIUs and in defining the number and types of SIUs.

In addition to the capabilities that an SIU may possess to implement propulsion system requirements, it may possess capabilities required by other user systems or by the DM&C subsystem such as transmission error detection and protection, electrical power conditioning and distribution for internal use, electrical power control, and self-checking. The requirements for these capabilities shall be derived from the applicable program and subsystem requirements.

3.2.1.6 Dedicated Remote Processors - Dedicated remote processors can be employed to perform the detailed checkout, monitoring, and control functions of certain major subsystems of the Space Shuttle, such as the main and airbreathing engines. The communication between remote processors and the CCC is limited to high level commands such as engine start, thrust level, and engine shutdown, and responses such as self-check status, malfunction detection data, and performance data to be recorded. The allocation of capabilities to the remote processors and their associated SIUs and sensors shall consider the criteria factors of Paragraph 3.2.2.

3.2.1.7 Recorders - Recording capability can be in the form of vehicle data storage devices, system or subsystem dedicated recorders, and/or CCC memory. Dedicated recorders can be used to accommodate subsystems that require recording of large quantities of performance data for postflight analysis. Similar data from other subsystems may be recorded on the vehicle data storage devices. Data that must be retrievable during flight, such as system status, shall be recorded in the CCC memory, or in the vehicle data recorder if it has inflight data retrieval capability.

3.2.1.8 Crew Controls and Displays - Manual controls for the propulsion systems provide for inputs such as thrust level selection for the airbreathing engines, control of the attitude control and maneuvering thrusters, and manual override capabilities as required. Crew displays of propulsion system data provide information to the crew relating to propulsion system status, hazard warnings and such other data as may be required to assist the crew in determining requisite actions. Visual data displays may be augmented by audio or visual alarms.

3.2.2 Allocation of Functional Capabilities - The functional capabilities that are required to perform the checkout and monitoring function for the Space Shuttle propulsion system are described in Section 3.1. The implementation of those capabilities shall be accomplished in accordance with the guidelines of this paragraph. The implementation of the checkout and monitoring function shall consist of allocating the required functional capabilities to the various onboard and ground elements that are candidates for incorporating those capabilities. The allocation of functional capabilities shall be accomplished through tradeoff analyses that include as criteria the requirements derived in Section 3.1, the Space Shuttle program requirements, vehicle subsystem requirements, and the implementation guidelines contained herein. The implementation approach is outlined in Figure 3.2.2-1.

3.2.2.1 Capability Requirements and Implementation Candidates - Section 3.1 identified data acquisition, data processing, recording, display, and stimuli generation as capabilites that are requisite to satisfying the checkout and monitoring function requirements for the propulsion systems. The matrix of Figure 3.2.2-2 reduces those capabilities to their basic functions and shows the relationship between them and the elements that are candidates to incorporate them. The requirements for these basic functions and their derivations are discussed in subsequent paragraphs.

3.2.2.1.1 Data Acquisition - Data acquisition includes the sensing of a propulsion system measurement parameter (whether it is from a sensor or a crew control) and any signal conditioning required to be performed to put the data into a form which is usable in subsequent calculations or comparisons, or for another purpose such as recording or display. Calculations or comparisons may be done by a remote unit or by the cental computers. Implicit in data acquisition is the transportation of data from one element to another, the conversion of data from one form to another that transportation requires, and any switching involved to acquire the desired data. The measured parameter tabulation formulated in Paragraph 3.1.2.2.4 shall be included in the criteria to implement these fundamental functions. The translation of the entries of the measured parameter tabulation into implementation criteria is shown in Table 3.2.2-1. For the purposes of this document, functions such as data formatting and data validation are considered the responsibility of the avionics system and shall not be further discussed herein. (While a dedicated remote processor or comparable unit may be assigned to the propulsion system, it is basically an avionics unit and its non-propulsion originated characteristics would be governed principally by avionics design criteria.)

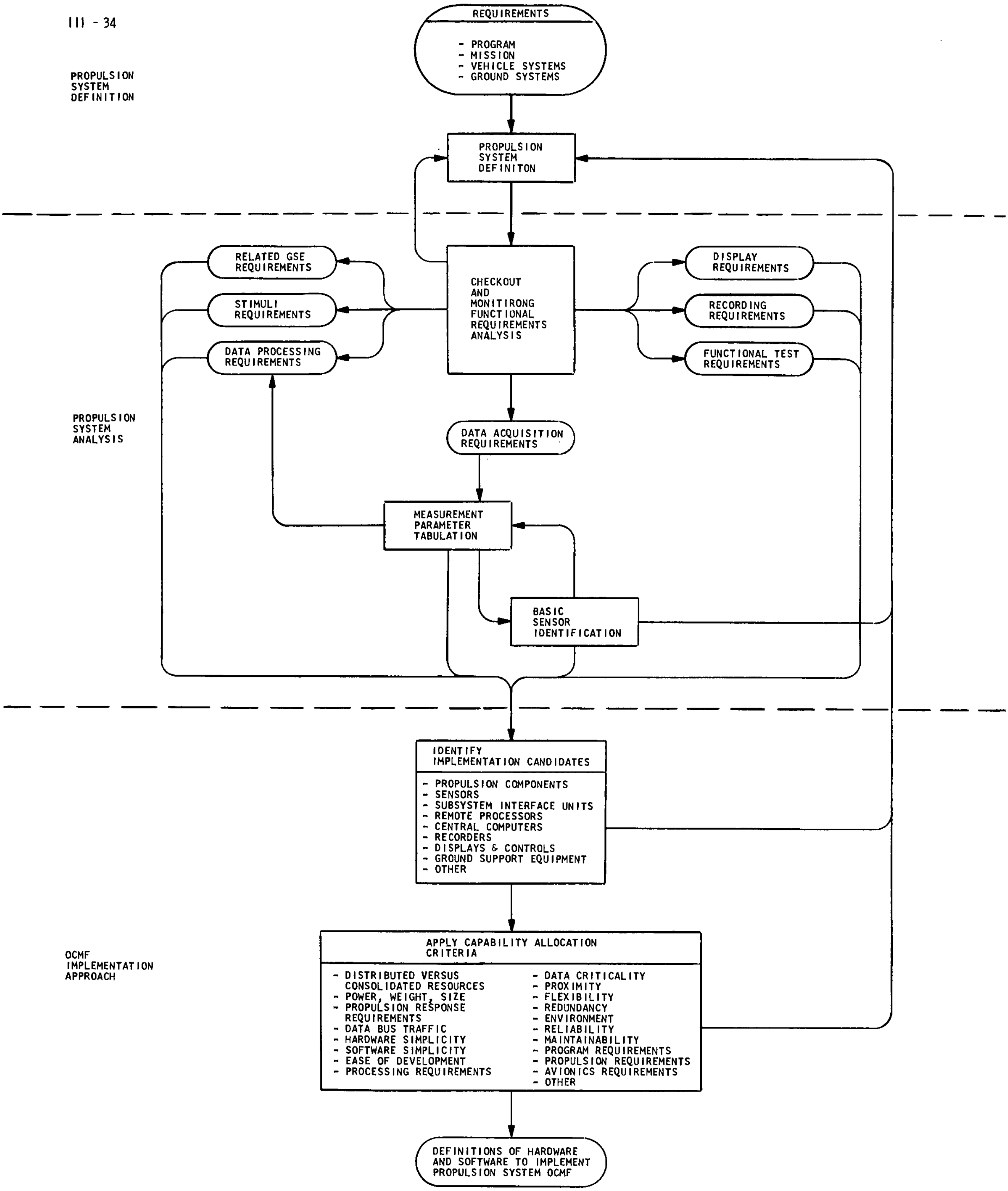

FIGURE 3.2.2-1 PROPULSION SYSTEM ANALYSIS & OCMF IMPLEMENTATION APPROACH

FUNCTIONAL CAPABILITY / FUNCTIONAL ELEMENT	SENSOR	SUBSYSTEM INTERFACE UNIT	DATA BUS	HARDWIRE	CENTRAL COMPUTER OR REMOTE PROCESSOR	DISPLAY AND ALARM	RECORDER	GROUND SUPPORT EQUIPMENT	CREW
SENSE	X	X			X			X	X
TRANSPORT			X	X				X	
CONDITION	X	X			X			X	X
SWITCH		X			X			X	
CALCULATE		X			X			X	X
COMPARE	X	X			X			X	X
STIMULATE	X	X			X			X	X
STORE		X			X	X	X	X	X
REPORT						X		X	

Figure 3.2.2-2 Capability Requirements Versus Implementation Candidates

TABLE 3.2.2-1

TRANSLATION OF MEASURED PARAMETER TABULATION
ENTRIES TO IMPLEMENTATION CRITERIA

PARAMETER (Column 1)	The parameter type provides identification of the basic sensor type.
PROPULSION ELEMENT (Column 2)	The identification of the associated propulsion element leads to the definition of the propulsion component/sensor interface.
TIME OF ACTIVITY (Column 3)	Used to define the intervals and magnitudes of the peak demands on vehicle resources, i.e., data bus, processors, recorders, displays, and crew. Conversely, periods of low activity or inactivity are defined during which conservation of resources may be achieved through resource management.
RANGE AND UNITS (Column 4)	Used in the definition of required sensor ranges which may affect sensing element type; the definition of SIU, remote processor and/or CCC range requirements.
ALLOWABLE ERROR* (Column 5)	Used to define the combined accuracy of the sensors, SIUs, remote processors, CCCs and displays used to acquire data. *A function of data usage.
RESPONSE RATE (Column 6)	Used to define the required sensor response, system sample rates and system reaction times.
SAMPLE RATES (Column 7)	Used to determine hardware speed requirement, processing speed and magnitude, and vehicle data bus rates. Sample rates are used as criteria for allocation of processing capability to SIUs versus central computer.
DATA USAGE (Column 8)	Used in the definition of sensor type, recording and display requirements, basic data processing requirements, and vehicle data bus requirements. Also affects allowable error.

3.2.2.1.2 Data Processing - Data processing for the propulsion systems is basically comprised of the calculations and/or comparisons required to evaluate acquired data (whether done by a remote unit or the CCC), the calculations and/or comparisons required to determine an appropriate control signal, and the operations requisite to recording and displaying propulsion data including data tagging and routing. The fundamental data processing requirements for data evaluation shall be derived from the data use, allowable error, and response rate entries of the measured parameter tabulation of Paragraph 3.1.2.2.4. Similarly the basic processing for propulsion system control shall be identified in conjunction with the definition of stimuli requirements. Data processing requirements for recording and display shall be derived from the recording and display requirements of Section 3.1 and the implementation of those requirements per the guidelines of this section. Other data processing requirements shall be derived from the simulation of sequences, events, and conditions during ground operations.

3.2.2.1.3 Electrical Stimuli - Control of the propulsion system requires the generation and application of external stimuli in addition to data acquisition, data processing, display, and crew action. The stimuli requirements of the propulsion elements (such as solenoid valves) are identified in accordance with Section 3.1. Additional stimuli requirements shall be derived from the final sensor specifications. Sensor stimuli may include gating commands, self-check commands, and calibration reference signals.

3.2.2.1.4 Data Storage - The recording of propulsion system status, performance data, fault isolation data, operating history data, and the storage of propulsion system algorithms and control sequences derived from the analyses of Section 3.1 comprise the data storage requirements for the propulsion systems.

3.2.2.1.5 Data Reporting - The propulsion system parameters and conditions for which data reporting (crew displays and alarms) is required are identified by the analyses of Section 3.1.

3.2.2.2 Capability Allocation Criteria - The general criteria that shall be considered in the allocation of capabilities to onboard and ground equipment are:

- Space Shuttle program requirements

- Space Shuttle propulsion system requirements and characteristics

- Space Shuttle avionics requirements

- Space Shuttle environmental requirements

- Minimization of:

  New development requirements
  Ground support requirements
  Unique hardware, software, and procedures

- Maximization of:

  Modularity
  Commonality
  Maintainability
  Reliability
  Hardware and software simplicity

Another general consideration for the allocation of functional capabilities is that of ease of subsystem development; that is, the level of development possible at the subsystem level is largely dependent on the distribution of capabilities among the system elements.

The specific implementation criteria for the allocation of capabilities shall be established by conducting the tradeoff analyses described in the following paragraphs. These analyses principally establish criteria for the allocation of the signal conditioning and data processing capabilities among the sensors, subsystem interface units, remote processors and the central computers.

3.2.2.2.1 Sensors - Basic sensor criteria shall be derived from Columns 1, 2, 4, 5, 6, and 8 of the measured parameter tabulation (see Table 3.2.2-1). A determination of whether an analog or a discrete output is required from the sensing element can be made from that criteria. The results of that determination shall be used in the definition of the signal conditioning and data processing requirements for the parameter under consideration.

Evaluation of the relative merits of consolidated (SIU or remote processor) versus distributed (sensor) signal conditioning shall be a primary factor in determining the extent of signal conditioning to be incorporated into sensors. The advantages of distributed signal conditioning are increased redundancy and the ability to trim a signal conditioner to a particular sensor. The advantages of consolidated signal conditioning are reductions in the power consumption, weight, and size of the signal conditioning equipment. The selection of sensing element type shall be done in conjunction with the definition of the signal conditioning equipment required for that sensor and shall include consideration of exposure to the propulsion system induced and natural environment.

A determination of the extent to which data evaluation capability shall be incorporated into sensors shall be performed considering the usage of the sensor output data, the sensor output interface (see next paragraph), sensor mounting options, weight, power, size, redundancy, flexibility, vehicle data bus traffic, and data processing requirements.

An evaluation shall be made to determine whether a sensor output should interface directly with the vehicle data bus, or with an SIU or remote processor. Reaction time requirements for safety and control shall be a primary consideration in this evaluation. Other criteria to consider are the reductions in hardware power, weight, size, vehicle data bus traffic, and data processing requirements when the communication capability for a number of sensors is consolidated into an SIU or a remote processor versus the increase in redundancy and system flexibility with individually addressable sensors. The results of this evaluation shall be used in the definition of sensor electrical interfaces.

Sensor electrical interfaces shall also include the definition of interfaces for sensor control commands and sensor electrical excitation. Sensor output enable and/or sensor self-check command requirements are dependent on the capabilities allocated to the sensor. The interface(s) for sensor electrical excitation depend on the power requirements of previously allocated sensor capabilities, the requirements for calibration references, and the determination of the optimum allocation of power conditioning capability.

The mechanical interfaces of sensors with the propulsion elements shall be defined considering such aspects as accessibility, maintainability, environment, the effects of location on sensitivity and fidelity, calibration requirements, mounting torque, and the moments of externally mounted assemblies.

Sensor accuracy shall be specified in conjunction with the accuracies of the other onboard elements (SIUs, remote processors, central computers, displays) such that the total allowable error specified for the associated measured parameter is not exceeded. Error allocation shall account for error sources whether they are random or time progressive and the relative cost to design and maintain each error allocation to attain the most favorable long life/cost characteristics.

Final sensor specifications shall include: parameter type; sensing element type; range; accuracy; sensitivity; frequency response; environment(s); operational and service life; electrical and mechanical interfaces; physical limitations; self-check requirements; and calibration requirements and/or restrictions (including restrictions on adjustments).

The assignment of sensor outputs to SIUs or remote processors shall be done in conjunction with the definition of those units.

3.2.2.2.2 <u>Subsystem Interface Units</u> - The functional redundancy of the propulsion subsystem and proximity to those subsystems shall be primary considerations in the definition of the number of subsystem interface units (or portions thereof) assigned to service the propulsion subsystems.

Tradeoffs for the allocation of signal conditioning, data processing and stimuli generation are the principal criteria for establishing the types of SIUs that are optimum in accommodating the propulsion system requirements. Signal conditioning requirements shall be established through tradeoffs as described under sensors (Paragraph 3.2.2.2.1); that is, distributed versus consolidated signal conditioning where the results influence system power, weight, size, redundancy, flexibility, and failure detection capability. The amount of signal conditioning required shall also be considered in establishing the number of SIUs for propulsion system service.

Data processing capability shall be traded off among sensors, SIUs, and central computers considering the actions, reactions and corresponding times required for propulsion system control; vehicle data bus traffic rates; central computer processing requirements; system power, weight, and size; system reliability and redundancy; ease of fault detection, fault isolation, and redundancy management; and simplicity of software development.

The extent of electrical power conditioning and distribution by SIUs for propulsion system stimuli or excitation shall be determined from the control requirements (both functional and checkout dictated) identified in Section 3.1. The extent of electrical power conditioning and distribution for sensor electrical excitation shall be determined in conjunction with the allocation of sensor capabilities and error budgets and shall consider the relative merits of consolidated versus distributed power conditioning. The requirements for the generation of stimuli for sensor control shall also be determined in conjunction with allocation of sensor capabilities.

3.2.2.2.3 Remote Processors - The quantity and speed requirements of data processing for control and fault detection are driving factors in the determination of whether or not remote processors shall be dedicated to major propulsion subsystems. Another major consideration is that the use of remote processors permits greater development of major subsystems prior to system and vehicle integration.

The allocation of data processing, signal conditioning, stimuli generation, and electrical power conditioning and distribution capabilities to remote processors shall consider the same criteria used for the allocation of capabilities to sensors and SIUs with the exception that a remote processor should accommodate as much of the processing requirement of the associated subsystem as possible. External processing should be principally for system control or long term trend analysis and redundancy management.

The implementation of a remote processor shall also consider its proximity to the associated propulsion subsystem, the functional redundancy of the propulsion subsystem, the criticality of each interface with the propulsion subsystem, and the degree of flexibility that is required to accommodate potential changes in requirements.

3.2.2.2.4 Recorders - The implementation of the propulsion system recording requirements identified in Section 3.1 shall consider the peak rate of the propulsion system data to be recorded, the period of time for which data must be retained, the total recording capacity required for propulsion system data, the requirement to provide in-flight retrieval of propulsion system status and fault isolation data, the requirement to adequately tag data for postflight evaluation, and the flexibility to accommodate changes in recording requirements based on mission requirements or on system trends.

3.2.2.2.5 Displays - The implementation of the propulsion system display requirements identified in Section 3.1 shall consider the criticality of the data as a principal factor in determining the type and redundancy of the reporting device(s) to be used. In addition to data criticality, the implementation of displays for propulsion system data shall consider the mission time, event, or time duration during which the display is required, the crew action required as a result of the display, the location of a display relative to other displays on which related data is presented, and the desirability of augmenting critical displays with alarms.

3.2.2.2.6 Data Bus - In addition to fulfilling the requirements of other vehicle systems, the configuration of the vehicle data bus shall accommodate the propulsion system checkout, control, and monitoring requirements identified in Section 3.1 and shall be compatible with the allocation of functional capabilities for those requirements as determined by the guidelines of this section. The data bus design shall consider the reaction time requirements of the propulsion system, the criticality of accurate transmission of propulsion system commands and responses, the peak data traffic requirements of the propulsion system in conjunction with the requirements of the other vehicle systems, and the flexibility to accommodate changes in requirements.

3.2.2.2.7 Central Computer Complex - The implementation of the vehicle central computer complex shall use the propulsion system requirements derived in Section 3.1 and the allocation of capabilities defined in this section as criteria. The definition of central computer data processing requirements for propulsion shall be made in conjunction with the allocation of data processing capability to the sensors, SIUs, and remote processors. The propulsion system checkout, control and monitoring requirements shall be included into the criteria for determining central computer instruction repertoire, instruction execution time, memory size, redundancy, and operational flexibility.

3.2.2.2.8 Ground Support Equipment - The extent to which the checkout and monitoring function requirements of the Space Shuttle propulsion systems are implemented by ground support equipment shall be determined by tradeoff analyses considering:

- Space Shuttle turnaround time and maintenance concepts
- Space Shuttle capability to land at a remote site
- Postflight checkout and evaluation requirements
- Maintenance retest requirements
- Preflight checkout and functional testing requirements
- Inflight versus ground requirements
- Available airborne technology
- Size, weight, and power consumption of the necessary onboard equipment
- Safety
- Crew participation

4.0 COMPLIANCE VERIFICATION

This section identifies the approach by which the intent of this document shall be verified. It delineates the documentation requirements of the contractor and the functions of the Procurement Agency in ensuring that the requirements of the onboard checkout and monitoring function are completely and accurately defined and that all appropriate criteria are considered in the implementation of those requirements.

The contractor shall satisfy the requirements of this section in addition to all of the detailed requirements defined in the statement of work or other parts of the contract.

Table 4.0-1 references the paragraphs of this section to the applicable paragraphs of Section 3.0.

The contractor shall develop and implement a Compliance Verification (CV) plan to effectively support the development of the OCMF. The CV programs of the contractor and his subcontractors shall be subject to continuous evaluation and inspection by the Procurement Agency during all phases of the contract to verify that the requirements of the CV program have been met. The contractor shall provide the Procurement Agency with information, documents, and records in the performance of his duties.

4.1 Compliance Verification Plan - The contractor shall implement a Compliance Verification Plan responsive to the requirements of this document. The plan shall describe a documented system for verifying contractor compliance with the requirements of this document.

The CV plan shall be submitted to the Procurement Agency for approval within the time interval specified in the contract. The format shall contain or reference CV procedures that describe all applicable activities in terms of what, how, and when the required operations will be performed. The plan shall include: charts and narrative statements that describe the contractor's organization; statements of duties, functions, and responsibilities relating to each CV task; and descriptions and definitions of the contractor's execution and management of each task. The tasks shall be described in terms of what, when, by whom, and by what methods each task will be accomplished. Applicable contractor policies and procedures shall be referenced in the plan.

4.1.1 Documentation Requirements - The documentation requirements of the contractor and the Procurement Agency related to OCMF shall be specified in the contract statement of work and the CV plan, and will include the requirements contained herein. Figure 4.1.1-1 shows the documentation flow.

TABLE 4.0-1

CROSS REFERENCE OF COMPLIANCE VERIFICATION PARAGRAPHS TO REQUIREMENTS PARAGRAPHS

SUBJECT	CV PARAGRAPH	APPLICABLE REQUIREMENTS PARAGRAPH(S) OR SECTION(S)
Program Requirements	4.1.1.2.1	3.1.2.1.1(a), 3.1.2.2.3.2
Mission Requirements	4.1.1.2.2	3.1.2.1.1(b), 3.1.2.2.3.2
Vehicle & Ground System Requirements	4.1.1.2.3	3.1.2.1.1(c), 3.1.2.2.3.2
Propulsion Hardware Definitions	4.1.1.3	3.1.2.1.2, 3.1.2.2.3.2
Control Seq. & Operational Logic Diagrams	4.1.1.4	3.1.2.1.3, 3.1.2.2.3.2
Failure Modes & Effects Analysis	4.1.1.5	3.1.2.2.2, 3.1.2.2.3.2
LRU Identification	4.1.1.6	3.1.2.2.1, 3.1.2.2.3.2
Checkout & Monitoring Functional Rqmts.	4.1.1.7	3.1.1(all), 3.1.2.2.3(all)
Display Requirements	4.1.1.7.1	3.1.1.2.5, 3.1.2.2.3.1(a), 3.1.2.2.3.2, 3.2.1.8, 3.2.2.2.5
Recording Requirements	4.1.1.7.2	3.1.1.2.4, 3.1.2.2.3.1(b), 3.1.2.2.3.2, 3.2.1.7, 3.2.2.2.4
Data Acquisition Requirements	4.1.1.7.3	3.1.2.2.3.1(d), 3.1.2.2.3.2, 3.1.2.2.4, 3.2.2.1.1
Stimuli Requirements	4.1.1.7.4	3.1.1.3, 3.1.2.2.3.1(e), 3.1.2.2.3.2, 3.2.2.1.3
Data Processing Requirements	4.1.1.7.5	3.1.2.2.3.1(f), 3.1.2.2.3.2, 3.1.2.2.4, 3.2.2.1.2
Related GSE Requirements	4.1.1.7.6	3.1.2.2.3.1(g), 3.1.2.2.3.2, 3.2.1.4, 3.2.2.2.8
Simulation Requirements	4.1.1.7.7	3.1.2.2.3.1(h), 3.1.2.2.3.2
Inspection Requirements	4.1.1.7.8	3.1.1.4.2, 3.1.2.2.3.1(i), 3.1.2.2.3.2
Sensor Requirements	4.1.1.7.9	3.1.2.2.4, 3.2.1.2
Propulsion System Interface Rqmts.	4.1.1.8	3.1.2.1.1(c), 3.1.2.1.2, 3.1.2.1.3, 3.1.2.2.3.2, 3.2.1.3
Implementation	4.1.1.9	3.2(all)
Implementation Candidates	4.1.1.9.1	3.2.1(all), 3.2.2.1(all)
Capability Allocation Trade Studies	4.1.1.9.2	3.2.2.2(all)

	Contract Go-Ahead	Conceptual Review	PDR	CDR	Acceptance Review
Compliance Verification Plan	▽				
Guidelines for Incorporation of the Onboard Checkout & Monitoring Function for Space Shuttle	△				
Program, Mission, Vehicle and Ground System Requirements	△				
Propulsion Hardware Definition		▽	▽	▽	▽
Control Sequence & Operational Logic Diagrams			▽	▽	▽
Failure Modes & Effects Analysis			▽	▽	▽
LRU Identifications			▽	▽	▽
Checkout and Monitoring Functional Requirements Display, Recording, Data Acquisition, Stimuli, Data Processing, GSE, Simulation, Inspection, Sensor			▽	▽	▽
Propulsion System Interface Definitions		▽	▽	▽	▽
Implementation Candidate Identifications[1]	△		▽	▽	▽
Capability Allocation Trade Studies			▽ *	▽ **	▽

Legend: △ = Procurement Agency Supplied

▽ = Contractor requirement; approval required.

* = Definition

** = Results

Note: 1. Contractor requirement if not supplied.

Figure 4.1.1-1 Documentation Flow

4.1.1.1 Guidelines for Incorporation of the Onboard Checkout and Monitoring Function on the Space Shuttle - The Procurement Agency will provide the contractor with this document during contract definition.

4.1.1.2 Propulsion System Functional and Operational Criteria - These criteria shall include program requirements, mission requirements, and vehicle system and ground system requirements.

4.1.1.2.1 Program Requirements - The Procurement Agency will supply all applicable program requirements to the contractor at the time of contract go-ahead. Requirements, specifications, concepts, guidelines and restrictions on such items as failure tolerance criteria, abort criteria, and crew interface criteria shall be included. Program requirement changes shall be subject to the provisions of the contract.

4.1.1.2.2 Mission Requirements - The Procurement Agency will supply all applicable mission requirements to the contractor at the time of contract go-ahead. The mission requirements shall include the mission timelines, sequences of event, and objectives for each mission phase. Mission requirement changes shall be subject to the provisions of the contract.

4.1.1.2.3 Vehicle and Ground System Requirements - The Procurement Agency will provide the contractor with descriptions of the propulsion system functional operating requirements on a mission phase basis. These requirements will be supplied at the time of contract go-ahead and shall include: propulsion system modes of operation and associated sequences, frequencies, and durations; definitions of propulsion system physical and functional interfaces with other vehicle systems, the launch facility, propellant loading system, and mechanical and electrical ground support equipment at the launch pad, the landing site, and in the maintenance areas. The level of definition of these items by the Procurement Agency will serve as baseline requirements from which the contractor shall develop detailed definitions and designs. Requirement changes shall be subject to the provisions of the contract.

4.1.1.3 Propulsion Hardware Definition - The propulsion system hardware definition shall consist of schematics, configuration drawings, and component definitions. The hardware definitions shall be submitted for Procurement Agency evaluation and approval at propulsion system conceptual, preliminary, and critical design reviews, and the documentation for the final propulsion system design shall be submitted during the propulsion system acceptance review.

4.1.1.3.1 Propulsion Conceptual Design Review - The contractor shall submit a conceptual propulsion system design to the Procurement Agency for evaluation and approval at the time specified in the contract. The conceptual design shall include complete schematics to the component level and system configuration diagrams. These schematics and diagrams shall show interfaces with other vehicle systems and with ground equipment.

The conceptual propulsion system design will be evaluated by the Procurement Agency for checkout and monitoring function considerations (in addition to all other considerations) to verify, at a minimum, that:

(a) The design complies with the specified failure tolerance criteria;

(b) Single point failures have been eliminated or identified;

(c) The design meets the specified functional and operational requirements.

4.1.1.3.2 Propulsion Preliminary Design Review (PDR) - The contractor shall submit a preliminary propulsion system design to the Procurement Agency for evaluation and approval at the time specified in the contract. Schematics, configuration diagrams, preliminary component and interface definitions shall be included in the review. The preliminary propulsion system design will be evaluated by the Procurement Agency for checkout and monitoring function considerations to verify, at a minimum, that:

(a) The design complies with the specified failure tolerance criteria;

(b) Single point failures have been eliminated or identified;

(c) The design meets the specified functional and operational requirements;

(d) The design is amenable to checkout and monitoring.

4.1.1.3.3 Propulsion Critical Design Review (CDR) - The contractor shall submit a detailed propulsion system design to the Procurement Agency for evaluation and approval at a critical design review. The propulsion system design will be evaluated by the Procurement Agency for checkout and monitoring considerations to verify, at a minimum, that:

(a) The design complies with the specified failure tolerance criteria;

(b) Single point failures have been eliminated or identified;

(c) The design is amenable to checkout and monitoring;

(d) The design meets the specified functional and operational requirements;

(e) The interfaces related to the checkout and monitoring function requirements have been completely and accurately defined.

4.1.1.3.4 Propulsion System Acceptance Review - The contractor shall submit the final propulsion system design to the Procurement Agency for evaluation and approval at the propulsion system acceptance review. The final propulsion system design will be evaluated by the Procurement Agency for checkout and monitoring considerations using the same criteria by which the design was evaluated for the CDR.

4.1.1.4 Control Sequence and Operational Logic Diagrams - The contractor shall submit these diagrams for Procurement Agency evaluation and approval during the propulsion system PDR, CDR, and Acceptance Reviews. These diagrams will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) All control logic is shown;

(b) All conditions for control are shown;

(c) All operating modes are shown;

(d) All redundancies are shown;

(e) All interfaces are shown;

(f) All failure reactions are shown.

4.1.1.5 Failure Modes and Effects Analysis (FMEA) - The contractor shall submit his procedures and ground rules for conducting the FMEA (for propulsion system checkout and monitoring purposes) to the Procurement Agency for evaluation and approval at the time specified in the contract. The contractor shall conduct the FMEA in accordance with the approved procedures and ground rules and shall submit the results to the Procurement Agency for evaluation and approval at the propulsion system conceptual, preliminary, and critical design reviews, and at the acceptance review. The level to which the FMEA shall be conducted for the successive reviews shall be identified by the ground rules and procedures. The FMEA results will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) All failure modes have been identified;

(b) The failure mechanisms are sufficiently understood to specify failure detection methods;

(c) The specified failure reaction times are correct;

(d) The specified failure effects are correct;

(e) Detection methods or recommended alternatives have been identified for all failure modes;

(f) The recommended failure detection method is compatible with the failure reaction time;

(g) The failure detection method is capable of faithfully identifying the specified failure mode and cannot create false alarms;

(h) The failure detection method has been sufficiently demonstrated to provide confidence in its use in this application;

(i) Redundancies have been accounted for and justified.

4.1.1.6 Line Replaceable Unit (LRU) Identifications - The contractor shall submit LRU identifications to the Procurement Agency for evaluation and approval at the propulsion system PDR, CDR, and acceptance reviews. The LRU identifications will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The LRU identifications comply with the Shuttle maintenance concepts and timelines;

(b) The LRUs are capable of being fault isolated;

(c) The identified LRUs have adequate accessibility;

(d) The LRUs have been optimally selected in terms of the number of mechanical and electrical attachments involved;

(e) Where practical, the LRUs do not contain components that are known to vary widely in life expectancy;

(f) The LRUs provide a logical breakout of redundant paths or elements;

(g) The LRU selection is logical in terms of minimizing ground equipment for post-installation retest requirements and simplicity in retest procedures.

4.1.1.7 Checkout and Monitoring Functional Requirements - The contractor shall submit the results of the propulsion system checkout and monitoring requirements analysis to the Procurement Agency for evaluation and approval at the propulsion system preliminary and critical design reviews and at the acceptance review.

4.1.1.7.1 Display Requirements - The display requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The display requirements are consistent with the program guidelines;

(b) The recommended display information is of real value to the crew;

(c) The recommended types of displays are adequate;

(d) The recommended display redundancy is consistent with the criticality of the information being displayed;

(e) The event or period for which the display has significance has been identified;

(f) The crew action associated with the display has been identified.

4.1.1.7.2 Recording Requirements - The recording requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The use of the recorded data has been identified and justified;

(b) The time interval for which data must be retained has been identified;

(c) Data that must be retrievable during flight has been identified as such;

(d) The mission period or event for which the data has significance has been identified;

(e) The peak rates associated with the data have been identified and justified.

C.2

4.1.1.7.3 Data Acquisition Requirements - The contractor shall submit the initial data acquisition requirements tabulation, the optimized list of measured parameters, and the rational justifying the retention or elimination of parameters to the Procurement Agency for evaluation and approval. The data acquisition requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) All parameters have been uniquely identified;

(b) The propulsion element with which the parameter is associated has been adequately identified;

(c) The parameter ranges and expected values for all conditions for which the data has significance have been completely identified;

(d) The total uncertainty within which the value of a parameter must be known has been specified and is compatible with the indicated data usage;

(e) Parameter response rates of significance have been completely and accurately specified;

(f) The specified sample rates are commensurate with the indicated response rates and reaction times;

(g) The use(s) of the parametric data have been identified and all uses have been justified;

(h) The time intervals, operations, or conditions for which the data is meaningful have been identified;

(i) All data sources have been evaluated and the listed parameters satisfy all of the checkout and monitoring functional requirements;

(j) Discriminants have been completely identified relating the recommended parameters to specific failure modes identified by the FMEAs;

(k) The parameter list includes operational conditions such as manual control settings;

(l) Measured parameters have been selected for all derived parameters and have been justified;

(m) Corrective actions have been defined for all identified parameters for which measurement techniques are unavailable.

4.1.1.7.4 Stimuli Requirements - The stimuli requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The specified stimuli requirements are consistent with the propulsion component definitions;

(b) The specified requirements meet all of the propulsion system control requirements;

(c) Sufficient speed and accuracy margins have been specified;

(d) All sensor stimuli requirements have been specified.

4.1.1.7.5 Data Processing Requirements - The data processing requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) Data processing requirements have been identified for each control, monitoring, recording, display, simulation, and data evaluation requirement;

(b) The frequency and required rate of processing has been specified for each requirement;

(c) The interval during which the specified processing is required has been identified;

(d) The processing requirements include identification of the data routing and tagging associated with the checkout and monitoring function.

4.1.1.7.6 Related Ground Support Equipment (GSE) Requirements - The related GSE requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The ground support items related to checkout and monitoring during postflight checkout and evaluation, maintenance retest, and prestart checkout have been identified;

(b) The recommended GSE items are compatible with the Shuttle turnaround time and maintenance concepts;

(c) Rationale has been provided to indicate why GSE was selected instead of onboard equipment.

4.1.1.7.7 Simulation Requirements - The simulation requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The simulation requirements cover all modes of propulsion system operation;

(b) Alternatives have been recommended where conditions have been judged to be impractical or not cost effective;

(c) The simulation is not so extensive as to degrade the effectiveness of the ground prestart checkout procedures.

4.1.1.7.8 Inspection Requirements - The inspection requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) Rationale is available justifying the selection of the recommended inspection technique over checkout by onboard equipment;

(b) The inspection requirements were included in the propulsion system design on which the checkout and monitoring requirements analysis was conducted;

(c) The inspection procedures have been integrated into coordinated postflight evaluation procedures.

4.1.1.7.9 Sensor Requirements - The contractor shall submit a candidate sensor list to the Procurement Agency for evaluation and approval at the PDR, a recommended sensor list and sensor specifications at the CDR, and sensor criteria and identification during the acceptance review. The sensor requirements will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The recommended sensor type is best suited to the accuracy, response, and environment requirements and to the intended data usage;

(b) The sensor interfaces have been completely and accurately defined;

(c) The recommended location and mounting technique is optimum in terms of the quality of the desired parameter data;

(d) Satisfactory sensor checkout and/or calibration procedures have been established;

(e) The recommended sensor redundancy is consistent with the program guidelines on critical data;

(f) Those sensors that must be line replaceable units have been identified as such;

(g) The recommended sensors have operational and service life ratings compatible with the intended application.

4.1.1.8 <u>Propulsion System Interface Definitions</u> - The contractor shall submit definitions of the propulsion system interfaces with other onboard and ground systems that involve propulsion system checkout and control to the Procurement Agency for evaluation and approval. The interface definitions will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The interface definitions completely specify all applicable characteristics such as magnitude, level, rate, polarity, phasing, force, torque, pressure, frequency, loading, etc;

(b) The interface definitions meet the applicable failure tolerance criteria;

4.1.1.9 <u>Implementation</u> - The implementation of the propulsion system OCMF requirements requires the basic identification of the functional elements that are candidates for implementing the OCMF, and the definition and conduct of trade studies to identify the optimum allocation of required OCMF capabilities to the selected implementation candidates.

Typical elements that are candidates for implementing the propulsion system OCMF requirements are defined in Section 3.2.1 and consist of propulsion system elements, sensors, vehicle avionics, other interfacing onboard systems, and related ground equipment. Of these elements, sensors, propulsion system elements, recorders, displays, interfacing non-avionics systems, ground support equipment, and the crew are elements that are required by all candidate configurations. However, the degree of usage of each element for implementing the OCMF requirements can vary from one configuration to another. Therefore, the primary task in identifying candidate elements for OCMF requirements implementation is the definition of the basic configuration of the avionics elements (data management and control subsystem in Section 3.2) that are required for data acquisition, data processing, data transportation, and the control functions of the vehicle subsystems.

The contractor's responsibilities in selecting implementation candidates will depend on the level of vehicle systems definition by the Procurement Agency. If the implementation candidates have not been sufficiently defined by the Procurement Agency, the contractor shall do so per the guidelines of Section 3.2. The Procurement Agency will evaluate the contractor recommended implementation candidates per the guidelines of Paragraph 4.1.1.9.1.

Procurement Agency approved implementation candidates shall be used by the contractor to define and conduct trade studies in which the propulsion OCMF requirements shall be allocated to the selected implementation candidates per the guidelines of Section 3.2. The definitions and results of these trade studies will be evaluated by the Procurement Agency per the guidelines of Paragraph 4.1.1.9.2.

The selected implementation candidates, together with the propulsion system checkout and monitoring function requirements and their approved allocations, shall become formal design requirements for the applicable onboard and ground systems. Other criteria, compliance verification, and quality assurance requirements governing the design, fabrication, and test of the affected systems shall be the subject of the appropriate system requirements.

4.1.1.9.1 Implementation Candidates - The contractor shall make the basic identification of the vehicle and ground system functional elements that are candidates for implementing the propulsion system OCMF requirements (and other vehicle system requirements) to the extent specified in the contract. The contractor shall submit his recommended implementation candidates to the Procurement Agency for evaluation and approval. The criteria by which the Procurement Agency evaluates the implementation candidates will include:

- Weight, cost, size, power requirements.
- Requirements of all vehicle systems.
- System complexity versus flexibility.
- System fault tolerance.
- Turnaround time objectives and maintenance concepts.
- Development risks.
- Reliability.
- Environmental protection and control requirements.

4.1.1.9.2 Capability Allocation Trade Studies - The contractor shall define and conduct trade studies to allocate the capabilities required for propulsion system checkout and monitoring to the selected implementation candidates. The trade study definitions and results shall be submitted to the Procurement Agency for evaluation and approval. The trade study definitions and results will be evaluated by the Procurement Agency to verify, at a minimum, that:

(a) The allocations satisfy the data acquisition, data processing, control, data storage and reporting requirements identified by the analysis required in Section 3.1 of this document;

(b) Reaction time requirements for safety and control have been met;

(c) Environmental requirements have been met;

(d) The desired degree of flexibility has been achieved;

(e) The specified failure tolerance criteria has been met;

(f) The allocations meet the reliability goals;

(g) Self-check and/or calibration requirements have been met;

(h) Ground versus onboard allocations are compatible with program objectives;

(i) Crew safety requirements have been met;

(j) The allocations are compatible with turnaround time objectives, maintenance concepts, and remote landing site requirements;

(k) Weight, cost, size, and power consumption have been given adequate consideration;

(l) New development requirements, ground support requirements, and unique hardware, software, and procedures have been minimized;

(m) The allocations lend themselves to modularity, commonality, maintainability and ease of development;

(n) The allocations do not result in excessive complexity or development risk;

(o) The allocations are consistent with the optimum sensor locations and mounting technqiues;

(p) The recommended allocations do not require excessive environmental control provisions;

(q) Equipment location in the vehicle has been adequately considered;

(r) The allocations are compatible with the requirements of other vehicle systems, including the crew;

(s) Mechanical and electrical interfaces have been completely and accurately defined;

(t) The allocations lend themselves to long term accuracy stability;

(u) The allocations provide adequate margin in operating and service life requirements;

(v) The recommended allocations are amenable to ease of fault detection and redundancy management.

This page not used.

5.0 NOTES

This section lists and defines terms and abbreviations used in this document.

5.1 Definitions - An alphabetical listing of definitions follows:

CAUTION AND WARNING DISPLAY: the technique used to alert and inform the crew of the existance of an abnormal condition.

CENTRAL COMPUTER COMPLEX: the primary system of data processing for the vehicle.

CHECKOUT: the function of determining the capability of an element or system to perform its specified functional operations.

COMPONENT OPERATING HISTORY DATA: data identifying the accumulated functional operations (such as numbers of cycles, time above a specified temperature, etc.) of a component.

CONTROL: the function of starting, stopping, changing or otherwise regulating the functional operations of an element or system.

CONTROL SEQUENCE AND OPERATIONAL LOGIC DIAGRAM: a system analysis tool that defines detailed sequences and conditions of operation of a system.

DATA ACQUISITION: the process of sensing, signal conditioning to a usable form and transporting data to its destination.

DATA PROCESSING: the calculations and/or comparisons required to evaluate acquired data and to determine appropriate commands, and the operations requisite to recording and displaying data including data identification and routing.

DERIVED PARAMETERS: a parameter whose magnitude is established by applying a mathematical relationship to other parameters. An example of a derived parameter is flow rate calculated from temperature (density) and differential static pressure.

DISCRIMINANT: the criteria by which acquired data is evaluated to judge the performance or operational condition of the corresponding propulsion system or element.

EMERGENCY DETECTION: the detection of an abnormal condition that can progress into a catastrophic effect.

<u>FAULT DETECTION</u>: the determination that an element or system is performing outside its specified functional operational limits.

<u>FAULT ISOLATION</u>: the identification of the element or group of elements that performed or is performing outside its specified functional operational limits.

<u>FAULT PREDICTION</u>: the determination made through trend analysis that the performance of an element or system has an unacceptably low probability of remaining within specified limits.

<u>FLEET TRENDS</u>: information pertaining to performance characteristics and maintenance requirements of the fleet of vehicles during successive missions.

<u>FUNCTIONAL ELEMENT</u>: an element that provides a function in addition to or other than structural integrity, and is capable of functional operation.

<u>FUNCTIONAL OPERATION</u>: the change of state or condition of an element or system such as a response to a control command.

<u>FUNCTIONAL TESTING</u>: checkout that is performed by inducing functional operations or a sequence of functional operations on an element or system.

<u>GROUND SUPPORT EQUIPMENT</u>: for checkout and monitoring, the equipment that is needed, in addition to the onboard equipment, to accomplish the checkout and monitoring functions.

<u>LINE REPLACEABLE UNIT</u>: an element or group of elements that can be removed, replaced and retested within the constraints of the vehicle turnaround cycle timeline.

<u>MAINTENANCE</u>: those functions and activities associated with restoring the vehicle to an operational condition between flights.

<u>MAINTENANCE RETEST</u>: the function of verifying the capability of a system to perform its prescribed functional operations subsequent to maintenance activities.

<u>MEASUREMENT</u>: a single source of data relating to the magnitude of a parameter.

<u>MEASURED PARAMETER</u>: a parameter that can be measured directly.

MISSION PHASES: the repetitive set of discrete, sequential ground and flight operations of the Space Shuttle.

MONITORING: the function of determining whether an element or system is performing its functional operations with specified limits.

PARAMETER: a physical characteristic, state or condition. Examples include position, temperature, and flow rate.

POSTFLIGHT EVALUATION: the function of identifying elements that require maintenance either because they have not performed their functional operations within specified limits, or because their trend of performance indicates that the specified performance will not be attained during the next functional operation or flight.

POSTFLIGHT SAFING AND PURGING: those operations conducted after landing to place the vehicle in a safe, inert condition. This operation can include venting pressure vessels, draining propellants and purging tanks and lines, safing and removing pyrotechnic devices, etc.

PRESTART: a period immediately prior to initiation of a functional operation of an element or system, either on the ground or in flight.

PRESTART CHECKOUT: an evaluation conducted just prior to initiation of a functional operation to assess the capability of the element or system to operate within specified performance limits.

POSTFLIGHT CHECKOUT: checkout performed during postflight safing and purging operations.

REDUNDANCY MANAGEMENT: the function of reacting to the detecting of an existing or potential fault by activating a redundant path, function or element to alleviate the condition.

REDUNDANCY VERIFICATION: assessment of the capability of redundant functional elements to perform their specified functional operations.

REMOTE PROCESSOR: a computer which performs data processing and control sequences in response to commands from the central computer complex.

SELF-CHECK: the process by which a functional element assesses its own operational integrity and readiness.

SENSOR: a functional element that responds to a physical quantity or event and converts that response to transmissible data which is proportional to the magnitude of the quantity or indicates the occurence of the event.

STATUS VERIFICATION: verification that parameters are within specified limits or at specified values.

STIMULUS: an excitation or forcing function that is applied from a source external to a functional element.

SUBSYSTEM INTERFACE UNIT: an intermediary that interfaces a user subsystem (e.g., a propulsion subsystem) to the vehicle avionics system. An SIU performs a control function by translating avionics system commands into stimuli for the user subsystem and acquires data from the user subsystem for use by other vehicle and ground systems.

TREND ANALYSIS: the identification of changes in performance of an element or system during successive functional operations or flights, and the evaluation of such changes to determine the probabilities of performance degrading outside specified limits in subsequent functional operations or flights.

5.2 Abbreviations - Abbreviations used in the text of this document are defined as follows:

OCMF	Onboard Checkout and Monitoring Function
LRU	Line Replaceable Unit
GSE	Ground Support Equipment
NASA	National Aeronautics and Space Administration
MSFC	Marshall Space Flight Center
DM&C	Data Management and Control
CCC	Central Computer Complex
SIU	Subsystem Interface Unit